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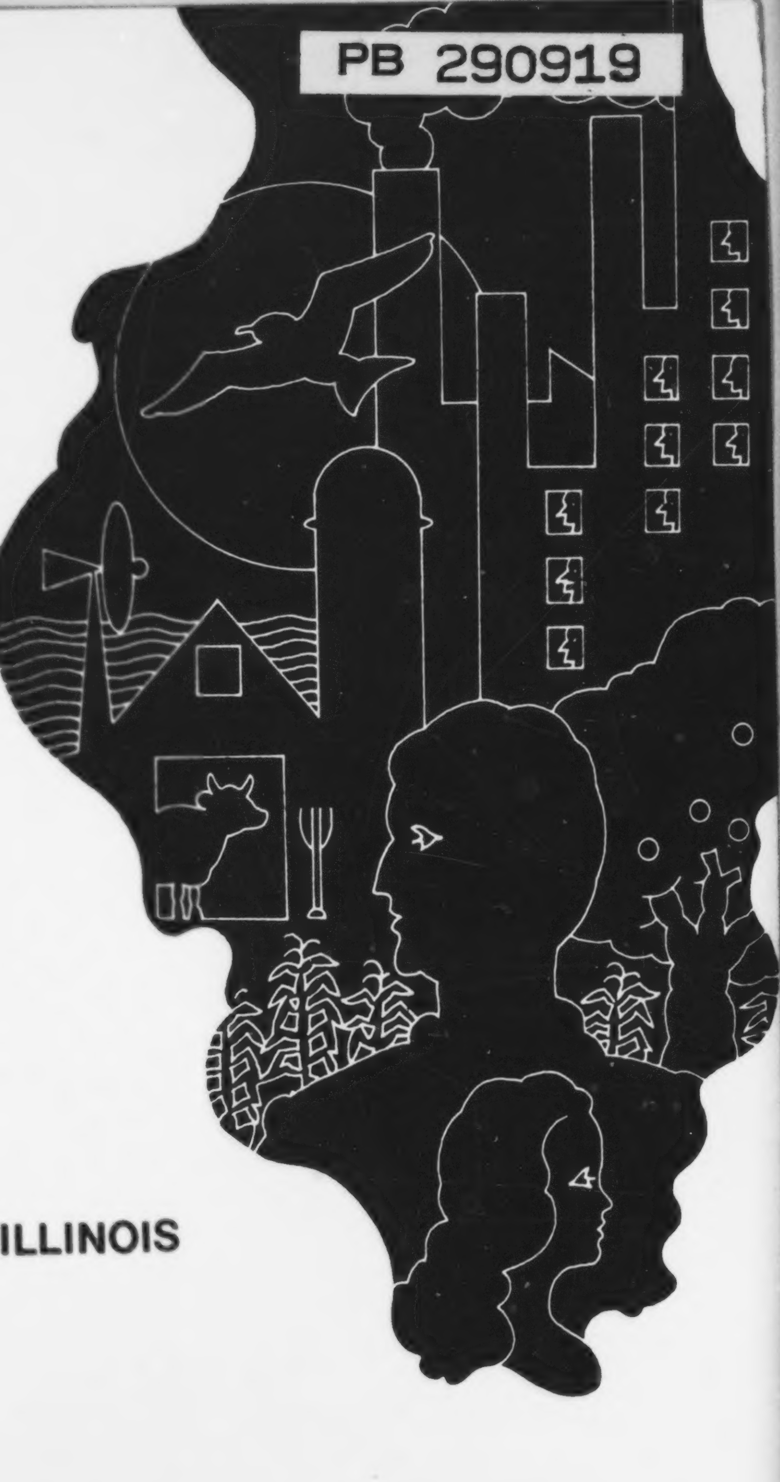

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DATA BOOK

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This document is the second of three resulting from a study by the INR of industrial used oil disposal and recycling in Illinois. These reports describe:

(1) an assessment of policies to encourage the reuse of industrial oils in Illinois
(2) a survey report on present practices of industrial used oil disposal and reuse
(3) an industrial manual to aid industries in starting oil reuse programs.

affecting the decline of the recycling industry are described in Chapter 4. Finally, the major technologies presently available or under development for the recycling or re-refining of oils were investigated and described.

This survey information has been organzied into four sections:

2.0 Illinois Inventory of Industrial Used Oils
3.0 Environmental Impacts of Oil Disposal Practices
4.0 Organization of Recycling and Re-refining Industry in Illinois
5.0 Recycling and Re-refining Technologies.

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USED OIL RECYCLING IN ILLINOIS:

DATA BOOK

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1. Introduction

This document is the second of three resulting from a study by the INR of industrial used oil disposal and recycling in Illinois. These reports describe:

1) an assessment of policies to encourage the reuse of industrial oils in Illinois
2) a survey report on present practices of industrial used oil disposal and reuse
3) an industrial manual to aid industries in starting oil reuse programs.

This survey document contains the results of several investigations into the source, nature and use of industrial used oils in Illinois. Specifically, a survey of several hundred industries (in cooperation with the Ill. Manufac. Assoc.) was carried out to determine the quantities of industrial used oil generated, their sources, disposal practices and prevalence of reuse.

A second component of this phase of the survey was to perform physical and chemical tests on samples of industrial used oil (with the cooperation of the University of Illinois Circle Campus, the Illinois Liquid Waste Haulers Association and Motor Oils Refining). The physical and chemical properties of the used oil samples were compared with those of virgin oils.

The nature of the relationship of oil disposal methods and chemical characteristics to the environmental impacts of this waste stream was then reviewed. A survey of the organization and operation of collection of used oils, re-refiners and reprocessors was also undertaken. Factors affecting the decline of the recycling industry are described in Chapter 4. Finally, the major technologies presently available or under development for the recycling or re-refining of oils were investigated and described.

This survey information has been organized into four sections:

2.0 Illinois Inventory of Industrial Used Oils

3.0 Environmental Impacts of Oil Disposal Practices

4.0 Organization of Recycling and Re-refining Industry in Illinois

5.0 Recycling and Re-refining Technologies.

2.0 Used Oil Inventory and Chemical-Physical Properties

Basic survey information on the quantities, path and chemical properties of used industrial oils is very scarce. While considerable work has been carried out to characterize used crankcase oils, the industrial used oils have not received nearly equal attention even though industrial oil sales for an industrialized state such as Illinois equal crankcase oil sales.

Characterizing the flow of industrial oils is complicated by the multiplicity of their uses - lubrication, quenching, hydraulic applications, cooling, etc. Collection and disposal techniques also vary widely. The used oil may be treated on-site, hauled away by the generator or hauled away by commercial carrier. It may then be reused or disposed of in a number of ways - reused as lubricant, fuel or dust control agent, disposed of at wastewater treatment plants, incinerators, landfills or sewers. Being able to determine the nature and quantities of these flows is a prerequisite to establishing cost-effective incentive programs to increase reuse. The quantity of flow and the comparative economics of recycling with present disposal techniques is a critical consideration in determining the success of such programs.

Physical and chemical data are also needed to accurately evaluate some of the problems incurred in both the recycling and disposal of these oils. Such evaluations are hindered by: (1) the lack of knowledge of used oil characteristics and recycling requirements to meet lubricant and fuel specifications, and (2) a poor data base regarding contaminant levels in industrial used oils which might cause environmental difficulties. Knowing the physical and chemical characteristics of the used oil, one can determine the extent to which oils can be reused within the plant and the treatment required for reuse, either at the plant site or at some centralized processing plant. Determination of the qualities and quantities of some of the used oil contaminants are also useful in assessing such potential environmental problems as those associated with use of the oil as a supplemental fuel or for road oiling and dust control, and landfill disposal.

2.1 Inventory of Used Oils in Illinois

The sales of lubricating and other oils in Illinois for 1973 and 1975 are listed in Table 2-1. As can be seen from the table there has been a significant decrease in total oil consumption from 1973 to 1975.

The main sources of used oil are the primary metal and metal-working industries, and the transportation sector, i.e., gasoline stations, workshops and garages where fleets are serviced. In industry, oils are used in wire drawing, metal cutting, the cold rolling of steel, hydraulic equipment and production processes. Many so-called "waste oil factors" have been utilized in previous studies to estimate the quantities of used oil produced.[1,2,3,4] The overall factor that is generally used is 0.50. Thus, if the total sales of industrial and automobile lube oils are 710 million liters, the used oil produced will be half that quantity or 355 million liters of oil.

Used oil factors published by the U.S. Environmental Protection Agnecy[3] for industrial and aviation lube oils are given below.

Table 2-1

Sales of Lubricating and Industrial Oils and Greases in Illinois

	Oils Liters x 10^3 (Gallons x 10^3)					Greases Kilograms x 10^3 (Pounds x 10^3)		
				Industrial				
	Total	Automotive	Aviation	Lubricating	Other	Total	Automotive and Aviation	Industrial and Other Greases
1973	670,134	290,354	1,011	253,016	125,753	19,896	9,222	10,674
	(177,050)	(76,712)	(267)	(66,847)	(33,224)	(43,863)	(20,331)	(23,532)
1975	547,265	254,110	1,147	179,693	112,316	19,320	8,836	10,483
	(144,588)	(67,136)	(303)	(77,475)	(29,674)	(42,592)	(19,479)	(23,113)

Source: "Sales of Lubricating and Industrial Oils and Greases", issued November, 1977, U.S. Department of Commerce, Bureau of the Census. These figures are the latest published information.

Table 2-2

Industrial and Aviation Lube Oils	Used Oil Factor
Hydraulic & circulating system oils	.42
Metal working oils	.42
Railroad engine oils	.53
Gas engine oils	.90
Aviation & other	.50
Other Industrial Oils	
Process oils	.10
Electrical oils	.90
Refrigeration oils	.50

Unfortunately, the origin of these numbers and other estimates is not well documented.

In Illinois, the Illinois Environmental Protection Agency and the Liquid Waste Control Association can account for less than 30 million liters of oil-based waste. This figure represents that amount which is legally transported and disposed of at licensed landfills. A significant fraction of this quantity is probably water and solvents.

Therefore, to develop more Illinois specific information on quantities and types of used industrial oils, an industrial survey was conducted. An industrial questionnaire was constructed to survey industries in the Standard Industrial Classification (SIC) categories 33 through 38 to quantify the production, and reuse and disposal of used oil in Illinois. The questionnaires were distributed to a representative cross section of companies in these categories which are the primary users of lubricating oils such as machinery lubricating oils, quench oils, cutting oils, etc. A description of these categories is given in Table 2-3 below:

Table 2-3

SIC Category	Description
33	Primary metals industries
34	Fabricated metal products, except ordinance, machinery and transportation equipment.
35	Machinery, except electrical
36	Electrical machinery, equipment and supplies
37	Transportation equipment
38	Professional, scientific and controlling instruments; photographic and optical goods; watches and clocks.

194 questionnaires were returned with sufficient information for analysis. The questionnaire and the survey methodology are presented in Appendix I.

A set of oil purchase factors and used oil factors (based on number of gallons per employee) was estimated for each SIC classification from the survey data. These factors were used together with employment data from the 1972 Census of Manufacturers in order to calculate a total industrial oil purchase figure and a used oil estimate for SIC 33-38. If we assume that the total purchased oil for these industries is approximately 50 million gallons per year, then, using the above procedure, the used oil generated would be 15 million gallons. The used oil contained about 54% water so that the waste stream volume associated with industrial used oil from SIC 33-38 is about 33 million gallons.

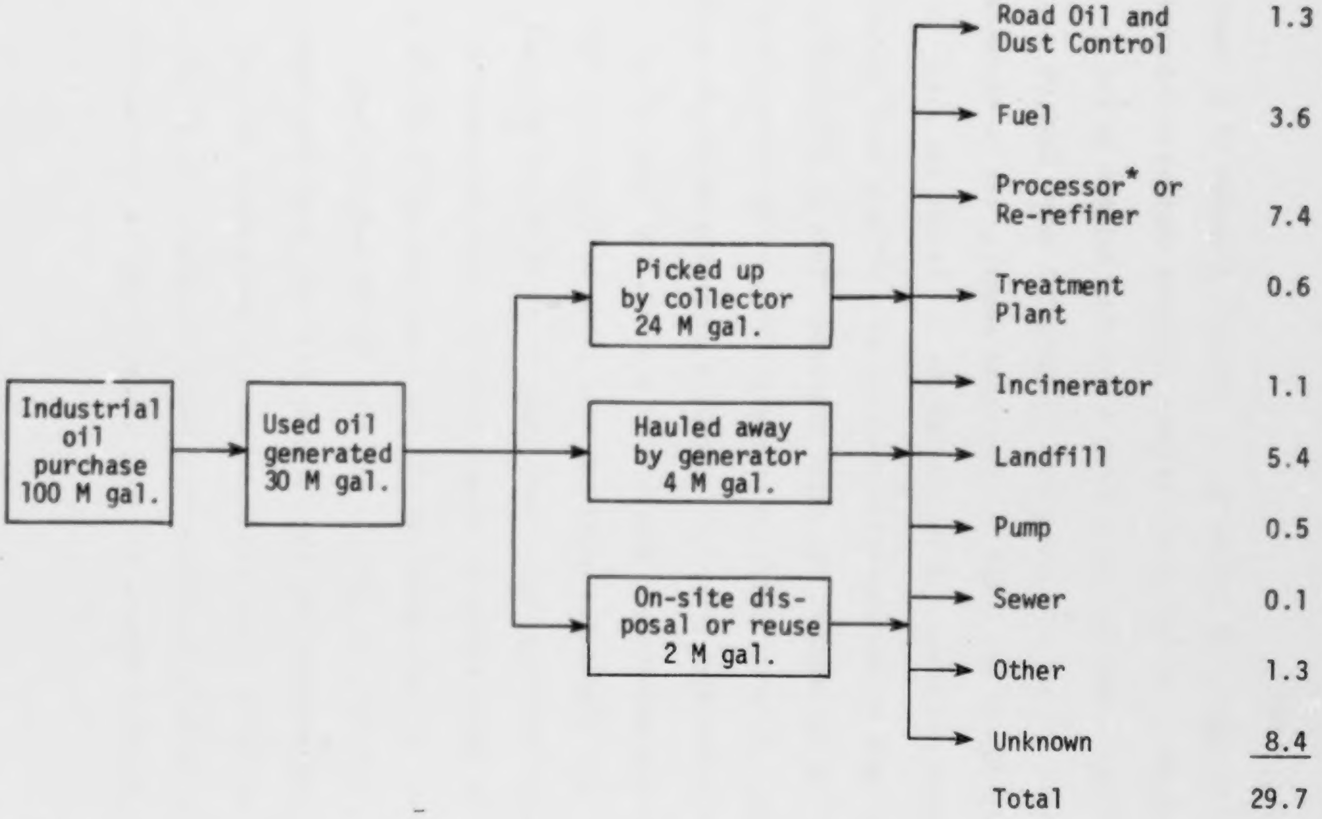
Since the total oil purchases in the state (using the 1973 estimate from Table 2-1) were 100 million gallons per year, the purchased oil estimates from SIC 33-38 represent 50% of total purchases. If other industries can be assumed to have similar used oil generator patterns to those surveyed, then the total industrial used oil generated per year in Illinois would be 30 million gallons per year; the associated waste stream, including water, would be 66 million gallons per year. Figure I-1 disaggregates these totals by type of oil.

In addition to providing an estimate of the total used oil in the state, the survey results provide information on the flow of used oil after the oil has been used for its primary purpose. A flow pattern of the quantities of oil recycled as a lubricant, reused for other purposes, or disposed of is presented in Figure 2-1. As presented in Figure 2-1, there are three alternatives a plant can use to remove the accumulation of used oil:

1. The oil can be hauled away by an independent collector.
2. The plant itself may haul the oil away.
3. The oil may be disposed of or reused on the plant premises.

The major methods of disposal of industrial oils can be classified as:

1. Recycling or processing of used industrial oils to a point where they can be re-employed as lube or hydraulic oil.
2. Road oiling and dust control - the spreading of oil on roads principally in order to reduce fugitive dust emissions.
3. Fuel supplement - the re-refining or blending of used oil with virgin oil for combustion.
4. Treatment Plant - treatment of oil-water mixture in wastewater treatment facility.
5. Dumping - disposal by spreading on water or in waterways.
6. Deposition on landfill - mixing of oil with solid wastes for burial on landfill.


Industrial oil purchase 100 M gal.
Used oil generated 30 M gal.
Picked up by collector 24 M gal.
Hauled away by generator 4 M gal.
On-site disposal or reuse 2 M gal.
Road Oil and Dust Control 1.3
Fuel 3.6
Processor* or Re-refiner 7.4
Treatment Plant 0.6
Incinerator 1.1
Landfill 5.4
Pump 0.5
Sewer 0.1
Other 1.3
Unknown 8.4
Total 29.7

*The principal product of the processor is fuel oil.

Fig. 2-1

7. Incineration - the combustion of oil for the purposes of volume reduction.
8. Sewage disposal - dumping of used oil-water mixtures into sewer systems.

Figure 2-1 presents the percentage of used oil disposed of by these methods. The majority of the survey returns indicate that most industrial plants have not been concerned with doing a material balance on the different types of oil used by the plant. Figure 2-1 shows that on the average only 30% of the total oil purchased annually can be accounted for when it leaves the plant. A portion of the oil leaves the plant in a product form, such as new machines requiring oil, while a small percentage of the oil is consumed in the plant processes, such as vaporization during quenching. A larger fraction of the oil leaves the plant as solid waste in filter cartridges or in oil absorbent materials which are sprinkled on the floor around machinery. However, in general, the total of all these potential oil flow paths would not come close to the missing 70%.

These results indicate that a very large fraction of the oil used every year in the plant cannot be accounted for by plant personnel at the present time. In rare cases, an oil audit has been performed for a single process, but this was usually not true for the entire plant.

The other explanations for the "missing oil" are sewer discharge, ground absorption in retention ponds and unusual cases where used oil is sold to waste haulers by unauthorized plant personnel. In all of these cases, inaccurate records are most probably kept on this used oil movement.

Theoretically almost all of the oil annually purchased by industry is recoverable. However, the percentage that is economically feasible to recover, ranges from 25% to 85% at the present time. The actual percentage which can be recovered depends on many variables including oil type, quantity used, level of contamination, plant plumbing, plant storage facilities and plant location.

One of the requirements for effective recovery of used oil is to segregate it from other industrial waste liquids and water. To accomplish this, however, it may be necessary to install storage facilities for the segregated oils. Survey results show that most plants do not segregate their used oils. More than half of the responding plants maintain used oil storage facilities of some kind, but these are not, in general, intended to support reuse programs. Rather, they serve as holding tanks for disposal of waste liquids. The estimated total statewide storage capacity for used oils is 4.3 million gallons. Used oil is stored for an average of 26 days. Since most of the estimated storage capacity is associated with waste liquid disposal rather than used oil recovery, it is fairly safe to assume, as the survey indicates, that oil segregation and storage of these separated oils for recycling is not widely practiced by Illinois industry.

From this analysis several observations may be drawn with respect to the patterns of used oil reuse and disposal in Illinois:

1) A relatively small fraction of oil purchased (30%) can be accounted for with respect to its reuse of disposal in the industrial plant.

2) Firms generally consider used oil in terms of a nuisance, to be disposed of by commercial haulers.

3) Industry is generally unaware of the fate of used oil once it leaves the plant (about 40% of the survey respondents did not know the fate of used oil they committed to commercial haulers).

4) Only a small fraction of used oil is recycled.

5) A large fraction of used oil is apparently disposed of at landfills by haulers.*

6) Storage and segregation of industrial used oils for the purposes of recycling are not widespread.

2.2 Chemical and Physical Testing

The chemical and physical testing of industrial used oils was carried out by first taking samples from storage tanks, lagoons and drums used for waste storage. The chemical testing was done at the University of Illinois Circle Campus. The analytical information supplied by the laboratory work at the Chicago Circle oil laboratory was supplemented by used-oil data obtained from the laboratories of the Motor Oils Refining Company and the Environmental Clearing House Organization (ECHO). These companies regularly test used industrial oil samples for various properties.

The physical and chemical tests that were applied to the used oil samples are described below. The results of these tests are presented in Appendix II.

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* Many of those industrial plants responding to the survey may be incorrect in thinking that their commercially hauled oil is being taken to the landfill, often it is given or sold to a reprocessor or fuel dealer.

Physical Tests

A) A.P.I. Gravity

Defined as $\frac{141.5}{\text{Specific gravity @ }60^\circ\text{F}} - 131.5$, where the specific gravity is the ratio of the density of material in question to that of water. This parameter provides a relative comparison of a given oil sample with another oil that has a different gravity. For example: the lower the A.P.I. gravity, the higher the viscosity of the oil; the higher the carbon residue, the heavier the weight; the lower the heat of combustion, the higher the density. A.P.I. gravity is a fair indication of the grade of the oil.

The A.P.I. gravity was determined by applying the ASTM standard test for A.P.I. gravity for crude petroleum and petroleum products (ASTM D-287).

B. Flash & Fire Points

The flash point is defined as the temperature at which the fuel oils produce enough vapors to cause a flash when ignited by an external flame. The fire point is a higher temperature, at which sufficient vapors are produced to cause continuous burning when ignited by an external flame. The flash and fire points represent limits of safety, in addition to being measures of volatility. Also, a wide temperature range in the open cup tester between the flash and fire points usually indicates blended oil.

The flash and fire points were established by applying the standard test specified for determining flash and fire points of petroleum products (ASTM D-92).

C. Pour Point

The pour point is a property that is related to viscosity. It is defined as the temperature at which an oil will just flow under standard conditions. It is important to know the pour point for oils because it gives an indication of the relative ease or difficulty of pumping the oil at any given temperature, and it may indicate the temperature at which an oil must be maintained when in storage tanks to insure proper flow into feed lines.

The pour point was determined by following the ASTM standard method of test for the pour point of petroleum oils (ASTM D-97).

D. Viscosity

Oil viscosity is defined as an oil's resistance to flow. This resistance decreases with increasing temperature. It can be determined by several methods. Two frequently used instruments for the measurement of viscosity are: the saybolt viscometer, which is the most commonly used, and the redwood viscometer. Since most of the current technical literature presents viscosity values in units of saybolt universal seconds (SUS), the standard method of test for saybolt viscosity (ASTM D-88) was used.

It is important to know the viscosity of fuel oil so that necessary adjustments in operating procedure can be made. The required pumping temperatures, atomizing temperatures, and oil pump pressures will be affected by the oil's viscosity.

In the case of lubricating oils, machine design dictates the viscosity required for efficient machine performance and maintenance. Factors such as the properties of bearing materials, surface pressures, machine speed, and operating temperatures are important criteria to be considered when choosing the viscosity of the lubricating oil.

E. Bottom Sediment & Water (BS&W)

BS&W was determined by following the procedure outlined in the ASTM standard method of test for water and sediment in crude oils and fuel oils by centrifuge (ASTM D-1796).

Water and sediment content are a serious problem in fuel oils. A high percentage of BS&W causes erratic and unsteady combustion, sparking, spitting, flashback of the flame, blocking and plugging of burner tips and screens, and erosion of burner tips and mechanical parts. Water may emulsify the oil and degrade its lubricating ability. It is therefore necessary to reduce the BS&W content of an oil to a few percent before using it. There are many methods available for determining the amount of BS&W in an oil sample. These include distillation to determine water content, extraction to determine the amount of sediment, and centrifugation to determine both water and sediment content.

Chemical Tests

A. Carbon Residue

Carbon residue can be a major source of trouble in burning used oil. Carbon deposits occur at burner tips and at the walls of small combustion chambers. These deposits are a less serious problem in large industrial furnaces.

Knowledge of the carbon residue in a fuel oil does not necessarily enable prediction of the rate and extent of formation of carbon or coke in a furnace.

The carbon residue was determined by applying the standard method of test for Conradson carbon residue of petroleum products (ASTM D-189).

B. Ash Content

Ash is the solid residue left when combustible material is completely burned. Ash deposits on engines and fuel oil burners cause wear damage to the equipment, thus it is important to know the amount of ash in an oil before using it.

The ash content of the used oil samples was measured in accordance with the ASTM standard method of test for ash from petroleum products (ASTM D-482).

C. Sulfur Content

Next to carbon and hydrogen, sulfur is the third most important element in an oil, even though it is present in much smaller amounts. It is not normally found as free sulfur, but in combination with other chemical materials such as carbon, hydrogen, oxygen, nitrogen, etc. In particular, it occurs in the form of hydrogen sulfide, H_2S, which attacks exposed steel parts and, which in the presence of oxygen and moisture, accelerates corrosion. Under normal and proper combustion conditions sulfur compounds are readily burned and do not affect furnace operation, but a high sulfur content fuel may cause air pollution problems, as well as equipment corrosion.

There are a wide variety of methods available for establishing the sulfur content of an oil. The method used by Motor Oils was in accord with the ASTM standard method for sulfur determining the sulfur content of petroleum products (ASTM D-1552).

D. Analysis for Metals

Metals normally found in an oil are barium, tin, silicon, zinc, aluminum, calcium, magnesium, sodium, lead, iron, copper, and cadmium. It is important to know the percentage of these metals in an oil because, in a lubricant a high metal content could cause wear in machinery, while in a fuel oil, certain trace of metal emissions present a health hazard.

Trace metal concentrations can be determined in several ways. Among these is included the ASTM standard method of test for the chemical analysis for metals in new and used lubricating oils (ASTM D-811). Motor Oils used atomic absorption to determine the trace metal content.

E. Heat of Combustion

Heat of combustion is one of the most important properties for fuel oil because it represents the quantity of heat that will be released when a unit quantity of the oil is burned. The heat of combustion of the used oil samples was measured by following the ASTM standard method of test for heat of combustion of liquid hydrocarbon fuels by bomb calorimeter (ASTM Designation D-240).

F. Acid Number

Acid number indicates the amount of uncombined acid in an oil. Since this property reflects the potential for equipment corrosion, it is an important consideration for any type of recycling program. It is expressed as the number of milligrams of potassium hydroxide required to neutralize one gram of oil.

The acid number of the used oil samples was determined by the standard method of test for acid and base number of petroleum products (ASTM Designation D-974).

The samples were prepared for analysis by centrifuging and then decanting the oil to separate it from the accompanying sludge and water. This was done after a part of each sample was set aside for the BS&W test. All tests were performed as described in the ASTM procedures except the BS&W; the volumes used in this test were half the volumes specified by ASTM.

2.3 Used Oil as a Lubricant

In terms of the properties presented, the following observations regarding the suitability of the tested used oils for lubricating purposes can be made.

1) API Gravity: 60% of the samples had API gravity values within the range of lubricant oils.
2) Ash Content: used oil samples generally were above virgin oils values.
3) Carbon Residue: the mean value of the used oil samples is within the range of virgin lubricant samples.

4) Bottom Sediment and Water: the used oil mean of 15% is much higher than the negligible amounts in virgin oils (indicating used oils would require treatment to reduce sediment and water contaminant levels prior to reuse).

5) Pour Point: the generally acceptable range is -40°F to 5°F, the used oil mean is well within this range. (If the temperature at which the oil is used can be controlled, higher values do not present a problem).

6) Flash and Fire Points: the mean value for the used oil just satisfies the minimum for lubricants. (For those used oils below the minimum, processing and possibly blending with virgin oils would be required to achieve satisfactory values for lubrication).

7) Viscosity: 95% of the used oils are within the viscosity range of lubricant applications, and thus viscosity is not a major obstacle to reuse if matched to the specific application range or if blended with virgin stock to meet requirements.

8) Acid Number: the acid number of the used oils is almost invariably well above the range of lubricants. It appears that most of the oils could not be used without first being neutralized.

In evaluating the above observations it is important to recognize the difficulty of determining the lubricating quality of an oil on the basis of a series of laboratory measurements. Many oils can be used as lubricants with less stringent specifications than those cited above. The final proof of acceptability as a lubricant can be obtained only by actual use. In general, used oils cannot be reused directly as lubricants without processing for several reasons, two of which are their low flash points and high bottom sediment and water content. Many oils are now being recovered through settling and filtration processes which lower bottom sediment and water content, lower carbon residue (important if oil is being reused as a fuel) and affect viscosity, flash, fire and pour points.

2.4 Used Oils as Fuel Supplements

The most important single determinant of the utility of a used oil for fuel is the value of its heat of combustion. Because the heat of combustion of most lubricants (approximately 20,000 BTU/lb) is about the same as for fuel oil, used oils appear to be useful as a fuel supplement. A comparison of the specifications (Table's II-5 and II-6) for several grades of fuel oil with the used oil sample analyses results, leads to the following observations.

1) Ash Content and Carbon Residue - the mean ash content and carbon residue of the used oil samples are substantially higher than that required of fuels. Deposits on burners impair combustion efficiency. Filtration, blending with virgin stock, or other processing seems indicated prior to use as a fuel.

2) Bottom Sediment and Water - the BS&W content of used oils tends to be significantly higher than the 2% limit specified for residual fuel oil. Settling and straining or blending would be required prior to use as fuels.

3) Pour Point - in general, the pour point of used oil is sufficiently low to permit its use as a fuel. Since virgin residual oil

must generally be heated in order for it to flow readily, a high pour point is not necessarily a serious limitation for a fuel oil.

4) Flash Point - the flash points of the fuel oils range from 38^{0}F to 65^{0}F, well below the minimum of 140^{0}F observed for the used oil samples. The higher flash point presents no obstacle to using used oil blended with virgin oil for fuel.

5) Viscosity - with few exceptions, the viscosity of used oil tends to be slightly higher than, but comparable to, that of the virgin product.

6) Trace Elements - the presence of sulfur and a variety of trace metals does not affect the performance of used oil as a fuel supplement, but these contaminants might present a health or environmental hazard when discharged in the flue gas. Dilution with virgin fuel oil may not always solve this environmental problem.

Studies by GCA's Technology Division and the Task Force on Utilization of Waste Lubricating Oils show some of the results of burning used oils. The used oils were used as a virgin fuel supplement, with a maximum of 15% used oil. Results showed that no unusual damage occurred to the equipment and no unusual maintenance was required as a result of the burning of used oils. (Based on limited information, the American Petroleum Institute (API) report also concluded that the flue gases were environmentally safe).

Several other studies conducted to examine the reuse of oil as a fuel, indicate that, in general, it is impractical to burn only used oil without prior treatment because of equipment damage, maintenance problems, and flue gas emissions when used directly. But when used oil is used as a fuel supplement at concentrations up to 25% of the total fuel volume, the results have been satisfactory according to the published reports.* Boron, cadmium and titanium are significantly higher in used oil than in virgin residual fuel oil. Used oil also displays somewhat higher values for chromium, calcium, iron, molybdenum and manganese.

2.5 Conclusions

The physical and chemical characteristics of the used oils sampled from the metalworking industries exhibit a wide range of values. Table 2-2 presents the range of experimental results. These results indicate that the cost and extent of reprocessing will vary greatly. Low values of flash points, along with high bottom sediment and water, make use of used oils as lubricants unfeasible without treatment. Several plants now reuse their lubricants to some extent after settling, straining, and magnetic removal of some trace metals, etc.

Because the heat of combustion of used lubricating oils is the same as that of virgin fuel oil, the reuse of these oils as a fuel supplement is possible. The high ash content, carbon residue, and bottom sediment and water content may be lowered to a level acceptable for supplemental fuel oil use by removal of contaminated matter with settling and straining. This treatment, however, would not necessarily reduce the high metal content of the oils.

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*Further testing of stack effluents is now being conducted by the U.S. EPA (Used Oil Recycling Study - ETA Engineering and RECON Systems of Summerville, N.J.).

Table 2-2 Range of Experimental Results

	Maximum	Minimum
API Gravity	40.6	12.9
Ash Content (%)	17.0	0.0
Carbon Residue (%)*	1.9	0.0
BS&W (%)	90.0	0.0
Pour Point (°F)*	+59	-60
Flash Point (°F)	525	72
Fire Point (°F)	600	210
Heat of Combustion (Btu/lb)	20,863	8,300
Viscosity @ 100°F (SUS)	2,270	42
Viscosity @ 210°F (SUS)	145.8	10.8
Acid # (mg KOH/g)*	4.45	0.61
Sulfur (%)	1.0	0.0
Silver (PPM)*	0.6	0.1
Sodium (PPM)*	40	0
Zinc (PPM)	5,000	0
Copper (PPM)	461	0
Aluminum (PPM)	2,000	1
Barium (PPM)	550	0
Nickel (PPM)*	44	3
Chromium (PPM)	45	0
Calcium (PPM)	6,400	0
Iron (PPM)	5,100	5
Silicon (PPM)	2,500	1
Tin (PPM)*	45	0
Lead (PPM)	2,000	0
Phosphorus (PPM)	2,500	0
Boron (PPM)	69	0
Magnesium (PPM)	55	0
Vanadium (PPM)*	15	0
Molybdenum (PPM)*	2	0
Manganese (PPM)	250	0
Cadmium (PPM)	19	0
Titanium (PPM)*	110	0

* Performed only in Circle analysis

Much of the oil sampled could be re-refined to yield a base stock equal to a virgin base stock. Significant savings in re-refining costs could be achieved if oils were segregated within the plant and, more importantly, water and solvent streams kept separate from the oil stream.

3.0 Environmental Effects of Oil Reuse and Disposal

The most important health and environmental effects associated with used oil are encountered when it is reused directly either as a fuel supplement or dust control agent or is disposed via incineration, landfill or sewage treatment processes. The following discussion addresses the potential air, water and soil pollution effects of commonly employed reuse and disposal techniques. The most important of these are summarized in Table 3-1, below:

Table 3-1

Areas of the Environment Affected by Alternative Reuse and Disposal Methods

Method	Reuse	Direct Disposal	Areas of Environment Affected		
			Air	Land	Water
1. Burned as Fuel Supplement	X		X		
2. Incinerated		X	X		
3. Applied to Land		X		X	X
4. Deposited in Landfill		X		X	X
5. Used for:					
- Road Oiling	X			X	X
- Dust Control	X			X	X
6. Deposited in Lagoon		X		X	X
7. Deposited in Sewer		X			X
8. Injected into Deep Wells		X			X

We have already seen that used industrial oils contain a large number of contaminants and trace elements. Additives, such as those summarized in Table 3-2 below for the steel industry also complicate the waste management problems associated with used oil. Table 3-3 presents a fairly thorough compilation of the sources, contaminants, treatments, and disposal methods currently used for both crankcase and industrial oils.

3.1 The Health and Environmental Effects of Oil Reuse

3.1.1 Used Oil as a Fuel Supplement

There are many advantages in using used lubricating oil as a fuel, i.e., high heat content, low viscosity and sulfur content, as well as the removal of oily wastes from the environment. But along with the advantages, there are several disadvantages; the large amounts of dirt, water, and metals found in used lubes can cause equipment damage and air pollution problems.

Ambient environmental standards have not yet been established for most of the trace elements identified in the industrial used oil samples that were described in a preceding section of this report. Some references about their environmental effects can nevertheless be drawn by referring to current industrial exposure standards in order to compare used oil with virgin fuel oil and to establish the relative, if not the absolute, significance of each of the elements presented in Table 3-6. This approach follows generally the method described by Bela Vitez in the January 1976 issue of Power Engineering.

Table 3-4 presents typical trace element concentrations in virgin residual oil and ranks them in terms of their potential for producing

Table 3-2

Commonly Used Steel Mill Lubricants

LUBRICANTS	TYPES OF ADDITIVES THEY MAY CONTAIN	PURPOSE OF ADDITIVES
EP GREASES	SODIUM, CALCIUM, LITHIUM SOAPS	THICKENING AGENTS
	LEAD, SULFUR, CHLORINE OR PHOSPHORUS COMPOUNDS	WITHSTAND EXTREME PRESSURE
	POLAR COMPOUND	IMPROVE LUBRICATION ESPECIALLY IN PRESENCE OF WATER
	OXIDATION INHIBITOR	RESIST OXIDATION
HIGH TEMPERATURE GREASES	CLAY, SILICA OR BENTONITE	THICKENING AGENT AND TO PROVIDE HIGH DROPPING POINT
	OXIDATION INHIBITOR	RESIST OXIDATION
ROLL NECK GREASES (HAND PACKED)	CALCIUM SOAP	THICKENING AGENT
	GRAPHITE	ASSIST IN ROUGH LUBRICATION
CUP GREASES	CALCIUM SOAP	THICKENING AGENT
BALL AND ROLLER BEARING GREASES	RUST INHIBITOR	PREVENT RUSTING IN PRESENCE OF WATER
	SODIUM, LITHIUM OR MIXED CALCIUM AND SODIUM SOAPS	THICKENING AGENT
	OXIDATION INHIBITOR	RESIST OXIDATION
GEAR OILS - EP HEAVY DUTY	LEAD, SULFUR, CHLORINE, PHOSPHORUS COMPOUNDS	WITHSTAND EXTREME PRESSURE
	POLAR MATERIAL	IMPROVE LUBRICATION
	RUST INHIBITOR	PREVENT RUSTING IN PRESENCE OF WATER
	ANTI-FOAM COMPOUND	MINIMIZE FOAMING
GEAR OILS (CUTBACK)	PETROLEUM THINNER, CHLORINATED SOLVENT OR COAL TAR SOLVENT	PROVIDE EASE OF APPLICATION
HEAVY DUTY MOTOR OILS AND DIESEL LUBRICATING OILS	POUR DEPRESSANT	PERMIT EASY COLD WEATHER STARTING
	VISCOSITY INDEX IMPROVER	
	ANTI-FOAM COMPOUND	MINIMIZE FOAMING
	DETERGENT	KEEP ENGINES CLEAN
	OXIDATION INHIBITOR	RESIST OXIDATION
	CORROSION INHIBITOR	PREVENT BEARING CORROSION
TURBINE OILS	OXIDATION INHIBITOR	PROVIDE LONG OIL LIFE
	EXTREME PRESSURE AGENTS	WITHSTAND EXTREME PRESSURE
	RUST INHIBITOR	PREVENT RUSTING IN TURBINES
	ANTI-FOAM COMPOUND	MINIMIZE FOAMING
STEAM CYLINDER OILS (COMPOUNDED)	FATTY MATERIALS SUCH AS TALLOW, LARD, OR DEGRAS	PROVIDE BETTER LUBRICATION OF CYLINDERS UNDER WET STEAM CONDITIONS
	POUR DEPRESSANT	PERMIT EASIER HANDLING AT LOW TEMPS.
RUSTPROOFING OR SLUSHING OILS	POLAR MATERIALS OR EMULSIFIERS	PROTECT STEEL FROM RUSTING
RUSTPROOF COMPOUNDS (HEAVY)	POLAR MATERIALS, EMULSIFIERS OR CERTAIN SALTS	PROTECT STEEL FROM RUSTING
THREAD COMPOUNDS	POWDERED LEAD, COPPER, ZINC AND GRAPHITE	PREVENT GALLING OF THREADS PROVIDE GOOD SEAL UNDER PRESSURE
ROLL OILS	PALM OIL, TALLOW OR OTHER POLAR ADDITIVES	PREVENT SCRATCHING AND PROVIDE GOOD SURFACE FINISH
	SOLUBLE OIL OR OTHER EMULSIFIERS	PROVIDE EASE OF EMULSION FORMATION
SOLUBLE OILS	WATER SOLUBLE SOAPS AND SULFONATES AND OTHER EMULSIFIERS	PROVIDE STABLE EMULSIONS
	BACTERICIDE	ELIMINATE BACTERIAL ACTION IN EMULSIONS
	EXTREME PRESSURE AGENTS	WITHSTAND EXTREME PRESSURE
	RUST INHIBITOR	PREVENT RUSTING OF PARTS BEING PROCESSED
CUTTING OILS	SULFUR, PHOSPHORUS, CHLORINE COMPOUNDS	WITHSTAND EXTREME PRESSURE
	POLAR MATERIAL	GIVE ADHESION TO METAL
QUENCHING OILS	POLAR MATERIALS AND OTHER WETTING AGENTS	PROVIDE QUICK WETTING OF HOT METAL

SOURCE: LUBRICATION, "STEEL MILL LUBRICATION"

Table 3-3 Treatment and Disposal of Used Oils and Used Oil Residues

Used Oil or Residue	Source	Common Contaminants	Prime Contaminants Limiting Reuse or Simple Disposal	Principal Treatment and Disposal Methods Now Used (Disadvantages)
Automotive Lubricants (primarily crankcase oil, but contains transmission fluid, gear lubricants, hydraulic oil, solvents, brake fluid, possibly antifreeze)	Automotive Service Facilities (incl. discarded filters, and discarded vehicles)	Compounds of N, O, and Cl, water, gasoline, metal and carbon particles, Pb and other metal compounds.	Color and odor bodies (N and O compounds), suspended inorganics	1. Re-refining (residue disposal) 2. Fuel (tube deposits and particle emission) 3. Road oil and dust control (runoff)
Railroad Diesel Lubricants (primarily diesel lube, but may contain journal oil, gear lubricants)	Railroad Service Facilities	Similar to automotive lubricants, but no Pb	Color and odor bodies (N and O compounds), suspended inorganics	1. Re-refining (residue disposal) 2. Fuel (tube deposits and particle emission) 3. Road oil and dust control (runoff)
Truck Diesel Lubricants (primarily diesel lube but may contain transmission fluid, gear lubricants, hydraulic oil, etc.)	Truck Service Facilities	Similar to automotive lubricants but no Pb	Color and odor bodies (N and O compounds), suspended inorganics	1. Re-refining (residue disposal) 2. Fuel (tube deposits and particle emission) 3. Road oil and dust control (runoff)
Metal Working Lubricants (often emulsified with water)	Metal Working Plants	May contain fatty oils, S, N, Cl, F from original fluid + metal particles, oxidation and degradation compounds, sediment.	Metal particles, sediment	1. Chip extraction and settling at elevated temperature (oily solid wastes) 2. Settling & skimming (oily water waste & oil flocs and sludges) 3. Incineration (particle and other emissions)
Acid Sludge (93-98% sulfuric acid-oil sludge, on the order of 30% water-soluble)	Acid treating of waste oils to remove metals and other contaminants	H_2SO_4 Pb from crankcase oils, metals and metallic compounds, polymers, heavy oil residues	H_2SO_4 Pb, and other metals, oil	1. Landfill with or without mixing refuse (water pollution) 2. Lagoons (temporary)
Caustic Sludge (caustic, sodium, silicate, water, metals, oily sludge)	Caustic treating of waste oils to break emulsions	NaOH, Na silicates, Pb and other metallic compounds	Pb and other metals, oil	1. Landfill (water pollution, slow degradation) 2. Lagoons (temporary)
Spent Clay (oil and impurity contaminated clay cake)	Clay treating of waste oils to remove impurities, improve odor and color	Oil, organics containing N and O	Oil and other organics	1. Landfill (water pollution, slow degradation)
Pretreat Residues (sludge of oil, water, and inorganic residues)	Residues from settling, filtration, centrifugation, and other pretreatments	Pb from crankcase oils, other metals and metallic compounds, heavy oil residues (also discarded filter papers, cloths, filter aids)	Pb and other metals, oil	1. Landfill (water pollution, slow degradation)
Distillation or Extraction Bottoms (heavy oil fraction high in inorganics)	Distillation or extraction to concentrate nonvolatile contaminants	Pb from crankcase oils, other metals and metallic compounds, heavy oil residues, coke	Pb and other metals	1. Lagoons (temporary) 2. Asphalt 3. Fuel (air pollution)
Odors	Acid and other processing steps, water treatment, vents open tanks, leaks	May be trace hydrocarbons, solvents, organic acids, esters, O, N, S containing compounds, SO_2, SO_3, NH_3, etc.	Odors	1. Scrubbers (water pollution) 2. Vent to furnaces
Condenser Liquids (water from oil and stripping steam & light hydrocarbons; condensed steam and cooling water where steam jet vacuum with barometric condenser used)	Distillation Overheads	Phenols, other dissolved organics, oil	Emulsions, dissolved organics	1. Separators (poor efficiency, wet oil residue) 2. Separators/cooling towers/recycle (water pollution from blowdown)

Table 3-3 (continued)

Used Oil or Residue	Source	Common Contaminants	Prime Contaminants Limiting Reuse or Simple Disposal	Principal Treatment and Disposal Methods Now Used (Disadvantages)
Scrubber Waters (usually aqueous NH_3 or caustic with impurities)	Gas Scrubbing to eliminate SO_2, SO_3, and other volatile acids	NaOH or NH_4OH, SO_2 SO_3, water-soluble organics	Water-soluble organics	1. Recycle (water pollution from blowdown) 2. Acid treatment of blowdown (dissolved solids residue)
Runoff and Other Oily Waters	Oily Waters from spilled oils, leaks, cooling tower blowdown, other sources	Oil, dirt	Oil	1. Separators (poor efficiency, dirt/wet oil residues) 2. Impoundment for reuse (possible water pollution)
Ash and Coke	Furnace Tubes and other Piping	Metallic compounds, polymer, coke		1. Landfill (water pollution from ash solubles)
Other Industrial Oils (turbine oils, transformer oils, lubricants, hydraulic oils, heat transfer fluids, synthetic oils, etc.)	Industrial Plants, Power Plants (including discarded transformers and machinery)	Turbine oils: water oxidation products. Transformer oils: water oxidation products, polychlorinated oils. Gear oils: S, Pb, dirt, wear metal, water, oxidation products.	Metal particles, water, degradation products	1. See methods for automotive lubricants 2. Clay treating (spent clay waste) 3. Filtration (filter aid and particle waste) 4. Centrifugation (particle waste) 5. Recovery to prepare soluble oils 6. Incineration (air pollution)
Oily Water	Industrial Plants, Refineries, Marine Service Facilities, Fuel Terminals, Oil Spill Cleanup	Sand, dirt, salts, virgin oil metals such as V, Ni, Fe, foreign matter such as sorbents	Emulsions, soluble organics, foreign matter	1. Separators (poor efficiency, wet oil waste) 2. Biochemical treatment (expensive, sludge waste) 3. Combined municipal-industrial wastewater plants (pretreatment necessary, possible toxic materials, sludge waste) 4. Physical/chemical treatment (expensive, water contamination with chemicals)
Oily Sludges, Tars, Scums, Flocs	Tank Cleaning, Refineries, Coke and Petrochemical Plants, Oil Spills, Wastewater Treatment	Coke particles, S, N, O, halides, coagulents, water	Solids, S, N, O, halides	1. Incineration (possible air pollution) 2. Landfill (water and air pollution) 3. Ocean disposal (water pollution) 4. Lagoons (temporary)
Offspec and Contaminated Fuels	Refineries, Tank Cleaning, Airports, Pipelines, Fuel Terminals, Marine Service Facilities	Light hydrocarbons, sludges, solvents, water, salts, trace contaminants	Emulsions, sediments, color, odor	1. Distillation (water and residue problems) 2. Fuels (air pollution) 3. Incineration (air pollution)

Source: Reference 3

Table 3-4

Typical Trace Element Concentrations in Residual Oil and Rankings in Order of Their Potential for Having Harmful Effects as Emissions

Element	Ppm Median	TLV mg/m	Toxicity Factor	Toxicity Order
Sulfur	12,000	13	920	2
Silicon	300	---	---	---
Vanadium	180	0.1	1,800	1
Iron	150	10	15	10
Nickel	120	1	120	3
Calcium	120	5	24	8
Potassium	80	---	---	---
Aluminum	75	---	---	---
Magnesium	75	15	5	16
Sodium	35	2	17.5	9
Chlorine	12	3	4	18
Barium	4	0.5	8	13
Zinc	4	5	0.8	23
Phosphorous	4	0.1	40	4
Chromium	3	0.5	6	14
Cobalt	3	0.1	30	5
Manganese	2.5	5	0.5	24
Copper	2.5	0.1	25	6
Lead	2	0.2	10	11
Zirconium	2	5	0.4	25
Rubidium	2	---	---	---
Neodymium	1	---	---	---
Yttrium	1	0.5	2	20
Selenium	1	0.2	5	15
Titanium	0.4	---	---	---
Tin	0.3	0.1	3	19
Silver	0.2	0.01	20	7
Cerium	0.2	---	---	---
Thulium	0.2	---	---	---
Boron	0.3	15	0.02	33
Ruthenium	0.2	---	---	---
Bromine	0.28	0.7	0.4	26
Molybdenum	0.25	5	0.05	30
Cadmium	0.2	0.1	2	21
Platinum	0.02	0.002	10	12

Table 3-4 (Contd.)

Element	Ppm Median	TLV mg/m^3	Toxicity	
			Factor	Order
Iodine	0.15	1	0.15	28
Strontium	0.1	---	---	---
Praseodymium	0.1	---	---	---
Tellurium	0.1	0.1	1	22
Germanium	0.1	---	---	---
Gadolinium	0.1	---	---	---
Hafnium	0.05	0.5	0.1	20
Tantalum	0.05	---	---	---
Terbium	0.05	---	---	---
Osmium	0.01	0.002	5	17
Arsenic	0.02	0.5	0.04	32
Antimony	0.02	0.5	0.04	31
Lanthanum	0.02	---	---	---
Mercury	0.01	0.05	0.2	27
Erbium	0.01	---	---	---
Scandium	0.01	---	---	---
Ytterbium	0.01	---	---	---
Cesium	0.005	---	---	---
Tungsten	0.005	1	0.005	35
Uranium	0.002	0.2	0.01	34
Dysprosium	0.002	---	---	---
Samarium	0.002	---	---	---
Lutetium	0.001	---	---	---
Holmium	0.001	---	---	---
Iridium	0.001	---	---	---
Palladium	0.001	---	---	---
Europium	0.0003	---	---	---
Gold	0.02	---	---	---
Rhenium	0.002	---	---	---
Indium	0.0002	0.1	0.002	36
Nitrogen	700	---	---	---

Source: Power Engineering, January 1976.

harmful effects as emissions. The key parameter here is the toxicity threshold limit value (TLV). TLV is the time weighted concentration of a substance that a healthy worker can tolerate for a 7-8 hour workday and a 40 hour work week without known deleterious effects. The "toxicity" shown in the table is the ratio of observed concentration in oil to TLV for each element.

Table 3-5 compares the toxicity of 37 elements in air, oil, and coal and indicates their relative importance. A comparable table (3-6) was prepared for the elements contained in the used industrial oil samples described previously. This table indicates, in terms of relative toxicity, how the trace elements found in typical Illinois industrial oils rank in terms of their potential environmental effects. On this basis, the most important trace elements appear to be phosphorous, copper, lead, tin, and calcium. Sulfur is the least significant element on this list. This information becomes meaningful when it is related to corresponding data for #6 virgin residual oil, a common industrial fuel. Table 3-7 presents this comparison. It is evident from the table that the environmental effects of used oil are less than or comparable to those of residual oil with regard to sulfur, silver, sodium, copper, nickel, chromium, vanadium, and cadmium. On the other hand, potential toxic effects of zinc, barium, calcium, iron, lead, phosphorous, boron, magnesium, molybdenum, and manganese are significantly greater for used oil than for residual oil. Therefore, if used oil is burned as a fuel, measures must be taken to prevent the uncontrolled entrance of these metals into the atmosphere. If, however, the used oil is diluted in the proportions one part used oil to seven parts virgin oil, only zinc,

Table 3-5

Toxicity Ratings for 37 Elements in Air, Oil, and Coal

Element	Toxicity Order			Mean Air Conc. mg/m^3	Toxicity Factor		
	In Air	In Oil	In Coal		Air	Oil	Coal
Vanadium	1	1	4	660	6,600	1,800	400
Lead	2	11	18	500	2,500	10	50
Sulfur	3	2	1	10,000	770	920	2,000
Sodium	4	9	6	1,530	765	17.5	400
Calcium	5	8	3	3,000	600	24	500
Iron	6	10	2	4,000	400	15	1,500
Cadmium	7	21	26	40	400	2	20
Bromine	8	26	24	160	230	0.4	20
Copper	9	6	9	220	220	25	250
Chlorine	10	18	5	620	207	4	400
Silver	11	7	11	1.2	120	20	200
Magnesium	12	16	12	1,160	73	5	167
Zinc	13	23	19	300	60	0.8	40
Chromium	14	14	17	26	52	6	50
Mercury	15	27	20	2	40	0.2	40
Nickel	16	3	7	26	26	120	250
Antimony	17	31	30	7	14	0.04	1
Selenium	18	15	23	2.4	12	5	25
Cobalt	19	5	15	1.2	12	30	100
Arsenic	20	32	25	4	8	0.04	20
Manganese	21	24	28	25	5	0.5	3
Iodine	22	28	29	4	4	0.15	2
Tungsten	23	34	34	0.6	0.6	0.005	0.3
Indium	24	35	35	0.05	0.5	0.002	0.1
Phosphorus	--	4	--	--		5	--

Table 3-5 (Contd.)

Element	Toxicity Order			Mean Air Conc. mg/m^3	Toxicity Factor		
	In Air	In Oil	In Coal		Air	Oil	Coal
Barium	--	13	16	--		8	60
Zirconium	--	25	22	--		0.4	30
Yttrium	--	20	8	--		2	250
Tin	--	19	14	--		3	120
Boron	--	33	--	--		0.02	--
Molybdenum	--	30	32	--		0.05	0.4
Platinum	--	12	13	--		10	150
Tellurium	--	22	27	--		1	20
Hafnium	--	29	33	--		0.1	0.3
Osmium	--	17	21	--		5	40
Uranium	--	34	31	--		0.01	0.5
Beryllium	--	--	10	--		--	250

Source: Power Engineering, January 1976.

Table 3-6

Trace Element Concentrations in Illinois Used Oil Ranked in Order of Their Potential Health Hazard*

Element	PPM	PPM	TLV	Toxicity Factor		Toxicity Order	
	Mean	Max.	mg/m^3	Mean	Max.	Mean	Max.
Sulfur	0.44	1.40	13	0.03	0.11	19	19
Silver	0.10	0.60	0.01	10	60	13	14
Sodium	46.6	400	2	23	200	11	10
Zinc	219	5000	5	44	1000	8	7
Copper	58.3	1160	0.1	583	11600	3	2
Aluminum	67.1	2000	--	--	--	--	--
Barium	59.7	550	0.5	120	1100	5	6
Nickel	6.40	44	1	6.4	44	14	15
Chromium	7.90	45	0.5	16	90	12	12
Calcium	316	6400	5	63	1280	6	5
Iron	333	5100	10	33	510	9	8
Silicon	104	2500	--	--	--	--	--
Tin	12.5	140	0.1	125	1400	4	4
Lead	125	2000	0.2	625	10000	2	3
Phosphorous	307	2500	0.1	3070	25000	1	1
Boron	7.30	120	15	0.49	8	17	17
Magnesium	49.4	1000	15	3.3	67	16	13
Vanadium	5.20	19	0.1	52	190	7	11
Molybdenum	2.20	19	5	0.44	3.8	18	18
Manganese	21.0	250	5	4.2	25	15	16
Cadmium	2.70	21	0.1	27	210	10	9
Titanium	6.50	110	--	--	--	--	--

*Based on all samples reported in Tables II-1 through II-3.

Table 3-7

The Relative Toxicity of Residual Oil and Used Oil*

Product Element	Residual Oil (PPM)	Waste Oil (PPM)		Toxicity Ratio (waste/resid.)	
		Mean	Max.	Mean	Max.
Sulfur	920	0.44	1.40	5×10^{-4}	0.002
Silver	20	0.10	0.60	0.005	0.03
Sodium	17.5	46.6	400	2.66	22.9
Zinc	0.8	219	5000	274	6250
Copper	25	58.3	1160	2.33	46.4
Aluminum	--	67.1	2000	--	--
Barium	8	59.7	550	7.46	68.8
Nickel	120	6.4	44	0.05	0.37
Chromium	6	7.9	45	1.31	7.5
Calcium	24	316	6400	13.2	267
Iron	15	333	5100	22.2	340
Silicon	--	104	2500	--	--
Tin	3	12.5	140	4.17	46.7
Lead	10	125	2000	12.5	200
Phosphorous	40	307	2500	7.68	62.5
Boron	0.02	7.3	120	365	6000
Magnesium	5	49.4	1000	9.88	200
Vanadium	1800	5.2	19	0.003	0.01
Molybdenum	0.05	2.2	19	44	380
Manganese	0.5	21.0	250	42	500
Cadmium	2	2.7	21	1.35	10.5
Titanium	--	6.5	110	--	--

iron, boron, molybdenum, and manganese remain in the blended fuel in significant amounts.

Not all metals leave the furnace in the flue gases. Some form organic-metallic compounds which are left in the ash or form deposits which may have to be removed periodically from the tubes and burners.

Atmospheric lead is the only metal which has been studied in some detail. In a study by GCA,[5] 2,250 lb/hr of crankcase oil containing one percent lead were burned. The resulting three-month average of ground lead concentration one-half mile from the incinerator equaled 0.05 micrograms per cubic meter or one-fortieth of the concentration stated by the EPA to produce sufficient risk to public health (the incinerator had a lead collector efficiency of 50 percent, stack height of 100 ft and was operated 8 hours per day, 7 days per week). It is known that inhaling large doses of beryllium, barium compounds, organic phosphorus compounds, manganese or its compounds, zinc, and lead can be poisonous. But stack emission factors, source emission limitations or ambient standards for these metals have not been established. It has been estimated that when burning fuel oil containing lead, approximately 50% of the lead exits in the stack gases. Also, consideration should be given to the environmental impact of disposing of ash with a high metallic content.

3.1.2 Road Oiling/Dust Control

Road oiling and dust control are indirect methods for the disposal of used oil. Although virgin petroleum products are used for road oiling, a large fraction is used oil, which is generally cheaper than a specially compounded oil and thus more economically attractive in the short run. In 1974, it was estimated that 200 million gallons of used crankcase oils plus unknown amounts of other used oils were used annually in the U.S. for road oiling and dust control.

The oil is usually applied to rural dirt roads through drilled pipe spray headers mounted on tank trucks. The application rate is left to the discretion of the applier and ranges from .025 to .05 gallons per square foot of road, depending on road composition and dust conditions. Very little of the oil applied to the road actually remains, necessitating periodic reapplications. A road may be oiled from one to four times a year. In a study dealing with used oil applied to rural roads,[6] it was observed that one percent of the total oil applied to the roads remained in the top inch. The rest was lost in a number of ways, including being washed from the road by rain, leached through the road, carried away by the wind on dust particles, picked up by passing vehicles and carried elsewhere, biodegraded, and volatilized. The extent and rate of oil loss depends on road composition, weather conditions, the time of the first rain after oiling, the type and quantity of oil applied, road traffic conditions, and the ability of the road surface to biodegrade the oil. Around 25 to 30 percent of the oil applied to the road is lost by biodegradation, adherence to vehicles, and volatization. The remaining 70 to 75 percent leaves the road with water runoff and dust transport,[6] contaminating surface waters.

Oil which makes its way into a water system becomes a nuisance and, in sufficient quantities, a health and ecological hazard. Used oil enters water systems in many ways: direct discharge into waterways, dumping into storm sewers, washing off roadways into waterways (rainwater may scavenge oil from road surfaces and then percolate into the groundwater), or direct deposition on or in the ground.

There should be no oils or greases present in potable water supplies. A concentration of one part per million (ppm) of oil in water causes taste and odor problems.[1] Very small quantities produce scum lines on water treatment facilities, swimming pools, retention basins, reservoirs, and other containers.[7]

Fossil fuel hydrocarbons (oils) are stable in water and coat the surface with a thin film. One pint of oil can produce a slick approximately one acre in size. As little as 35 ppm of oil can be seen floating on water as a thin film. These surface oil films coat and destroy plankton and algae as well as aquatic insects. Photosynthesis and reaeration of the water are also affected. Each year many birds die after encountering large oil slicks. Water-impermeable compounds on their feathers are destroyed by the oil, leaving the feathers wet and oily. The birds, unable to fly, are trapped in the slick. Oil also inhibits egg-laying and hatching. Low concentrations of oil coat the gill filaments of fish, causing suffocation. Crayfish weighing 35-38 grams die in oil concentrations of 5 to 50 milligrams per liter within 18-60 hours.[7] Very small quantities of oil pollution can interfere with natural organic compounds used to convey information about the environment to aquatic organisms. A study of lobsters revealed that 0.9 milliliters of oil in 100 liters of sea water causes noxious odors in the lobster's environment leading to irregular feeding patterns.[8] The oil resulted in a considerable drop in the number of necessary lipids present in the water.

Along with the oil that leaves the road surface and is deposited into the surrounding ecosystem are heavy metals and other additives which are taken up by plants and consumed by animals, either by drinking contaminated water or by eating plants that have taken up metals. In Alberta, Canada in 1971, cattle were poisoned by drinking water containing lubricating oil from a road treated with an oil that contained triaryl phosphate as an additive.[9]

Due to the negative environmental effects resulting from the runoff of used oils from roads, the State of Illinois prohibits the use of any used oil for road oiling or dust control. Because this regulation is difficult to enforce, used oil is still widely used for road oiling and dust control.

Some drain oil and distilled drain fractions are used as cutting stocks in the production of asphalt.[10] As a result, lead, as well as other metallic compounds, are incorporated into the asphalt, coated by asphaltic materials.

3.2 The Health and Environmental Effects of Used Oil Disposal Practices

3.2.1 Licensed Landfill Disposal

The major problem of disposing of industrial waste oil to landfills is pollution of groundwater supplies. The majority of municipal water in Illinois is derived from groundwater sources contained in deep sandstone or shallow dolomite aquifers. (Shallow aquifers are most susceptible to groundwater contamination.) Contamination of the groundwater is therefore a major concern around landfill sites, where dangerous quantities of refuse leachate must be prevented from entering the groundwater. Petroleum contamination of groundwater is widespread, as confirmed by a study in

Maryland. Unlike surface water, groundwater can flow in any direction (there is no "downstream"). The extent of the contamination of groundwater resources is not visible, but can be assessed only through costly and extensive drilling of observation wells. The great number of water wells makes extensive chemical analysis for groundwater contamination impossible, and therefore, most contaminated wells are discovered only after complaints of water taste, odor, or noticeable effects on surface waters or vegetation.

Much of the soil in Illinois is composed of clay, shale, silt, and glacial till, which are relatively impermeable and retard the movement of refuse leachate. About 80 percent of the land in northeastern Illinois is suitable for sanitary landfilling without site modification.[11] The areas composed of sand or gravel, on the other hand, are quite permeable and thus are not recommended for landfill sites. The water saturation zone in Illinois is relatively high, usually within 5 to 10 feet of the ground surface. This results in the extension of many landfills below the saturation zone.

To handle special wastes such as oil, landfill operators must obtain a supplemental permit. These permits are granted for environmentally acceptable sites. In Illinois, there are about 47 of these special-waste land disposal sites. The number of permits for oil dumping varies from 5 to over 200 per special-waste landfill site.

The disposal sites are divided into three categories according to the degree of hazardous material allowed.[12] A "Type I" disposal site may accept special wastes considered to be very hazardous. It must be buffered by at least 10 feet of fine-grained soil with a coefficient of permeability no greater than 1 x 10^{-8} cm/sec or at least 10 feet of soil providing 500 years of containment. A "Type II" site may accept special wastes less hazardous than those accepted by a "Type I" site. The site must be buffered by no less than 10 feet of fine-grained soil with a coefficient of permeability no greater than 5 x 10^{-8} cm/sec or no less than 10 feet of soil providing containment for 250 years. A "Type III" site may accept municipal refuse and special wastes which are mainly biodegradable. It must be buffered with at least 10 feet of fine-grained soil with a coefficient of permeability no greater than 1 x 10^{-7} cm/sec or no less than 10 feet of soil providing containment for 100 years.

Liquid special wastes, including oils, may be deposited directly in the landfill or injected into a trench, providing there is vertical and horizontal containment. Landfill disposal of used oils is an environmentally safe method when properly regulated. This method of disposal is also economically attractive since it is relatively cheap. There has been a significant increase in the number of requests to dispose of industrial liquids and sludges at licensed landfills in Illinois. Between 1974 and 1975, the annual amount of these wastes disposed of in Illinois landfills increased from about 33 million gallons per year to 184 million gallons per year.[13]

3.2.2 Land Application

Used oil can be disposed by breaking it down into harmless products. This is accomplished by soil microorganisms. The used oil, particularly when it is contained in sludge, is spread atop the land, where it can be biodegraded. The soil microorganisms oxidize the oils or convert oily waste into cell protoplasm producing by-products of gases and humus (partially reacted organics) along with organic acids (an intermediate product). The bacteria and fungi which grow the fastest are those using hydrocarbons for food, mainly filamentous and yeast-like fungi and rod-shaped bacteria, particularly *Pseudomonas stutzero*. Some mineral nutrients important for microbial growth are carbon, hydrogen, oxygen, potassium, sodium, calcium, and especially nitrogen and phosphorus. Microbial growth and therefore oil decomposition is increased with the use of fertilizers, as shown in experiments conducted by Shell Oil Company.[14] Soil microorganisms favor neutral soil; therefore, soil which is acidic may require the addition of agricultural grade limestone as a neutralizing agent.

Temperature also plays a role in the oil decomposition rate. Oil decomposes much faster in warm than in cold climates. The optimum temperature for the incubation of most hydrocarbon-oxidizing organisms is reported to be 86°F. During the winter months oils for land spreading in Illinois could require storage. To provide oxygen for soil microorganisms, the soil is aerated by disking. This disking or stirring of the soil also disperses the hydrocarbon molecules, making them more readily available to microbial attack. Soil saturated with oil or water has its air spaces filled, reducing the oxygen available to soil microorganisms. Without sufficient oxygen the number of microorganisms are few, resulting in a very slow oil decomposition rate. Some hydrocarbons, such as waxes and heavy oils, are more resistant to decomposition, because less surface area is exposed to microbial attacks.

In a paper presented at the 5th International Water Pollution Research Conference[14] (1970), the concept of land application for the disposal of oily wastes was addressed. Although the paper examines the disposal of oily wastes from refineries rather than used oils, it does furnish some useful information about oil assimilation by soils. The paper states:

> Soils have been shown to provide a high degree of physical chemical, and biological treatment for organic wastes when the system is properly designed. Despite their demonstrated efficiency in assimilating wastes, land-spreading has never been used as extensively as it could be. Although used by many petroleum refineries, oily waste disposal by land-spreading has not been generally appreciated and exploited by sanitation and pollution control officials.
>
> Many investigators have shown that microorganisms occurring ubiquitously in soils will attack petroleum hydrocarbons when they are added to soil. Unfortunately the process is too slow for effective disposal of oily sludge or reclamation of soil after oil spills or leaks without some cultural practice to accelerate decomposition.

Oil, when discharged without adequate treatment or proper disposal, is a serious pollutant of water and land. In 1969, the Marathon Oil Company in Robinson, Illinois, used land spreading to dispose of oily sludge stored in two lagoons over a period of five years.[14] The sludge, consisting of 35 percent oil, was spread on the ground to a depth of about 4 inches. When the sludge was dry it was mixed with the soil by disking to a depth of about 18 inches. A rainstorm occurred before cultivation of the sludge and resulted in erosion of the oily sludge and its deposition in a small lake, killing some fish.

Plants may also be affected by such oil. Large applications of oil to land are often toxic to plants due to the narcotic effect that volatile fractions have on plants and the reduction of manganese to the toxic manganous form. Plants growing on the land-spread area may acquire high levels of metal ions. Trace metals may be found in many used oils. If oils containing trace metals are deposited on the ground, vegetation may be contaminated and eventually animals may eat this vegetation.

The British attempted to use municipal sewage sludge as a soil conditioner[15] until they discovered that the metal content of the sludge constituted a hazard to agriculture. Twelve years after the project was discontinued, vegetables grown on the soil still contained abnormally high levels of chromates, copper, nickel, lead, and zinc.[16] Land saturated with oil eventually returns to a productive state. Humble Oil Company near Houston, Texas land-spread oily sludge 4 to 5 inches thick; 3 to 4 months later grass was growing.[14] More oil may be added to the soil of a land-spreading site when the soil returns to a brown friable condition.

Other used oil components, such as aromatic hydrocarbons, may present problems because of their lengthy degradation process. In addition, many of the additives that are combined with industrial oils may cause adverse environmental effects if not properly treated before disposal. Additive compounds containing phosphates or phenols can adversely affect water quality. Minute quantities of phenols cause objectionable taste and odor in drinking water and induce cancer in lower animals.[17] Another additive found in hydraulic fluids, lubricants, etc. is polychlorinated biphenyl (PCB). This chemical tends to accumulate in all animal tissue, including that of humans. It is a suspected carcinogen and may cause birth defects and nervous disorders. A national ban on PCB will go into effect on July 1, 1979.

Favorable locations for land-spreading sites are those with deep, fine-textured soils which readily absorb oil, thereby reducing the chances of a contaminated water table. Clay subsoils also help prevent contaminated water tables. To reduce surface water contamination, the site should be flat with poor drainage. Indiscriminate dumping on porous, coarse, or shallow soils is likely to cause runoff water pollution. Figure 3-1 indicates the volumes of soil required to immobilize different quantities of oil, based on a soil porosity of 30 percent. The following equation can be used if specific oil and soil characteristics are known.[18]

$\frac{0.2 \times V}{P \times SR}$ = Cubic yards of soil required to attain immobile saturation.

V = volume of oil (barrels)

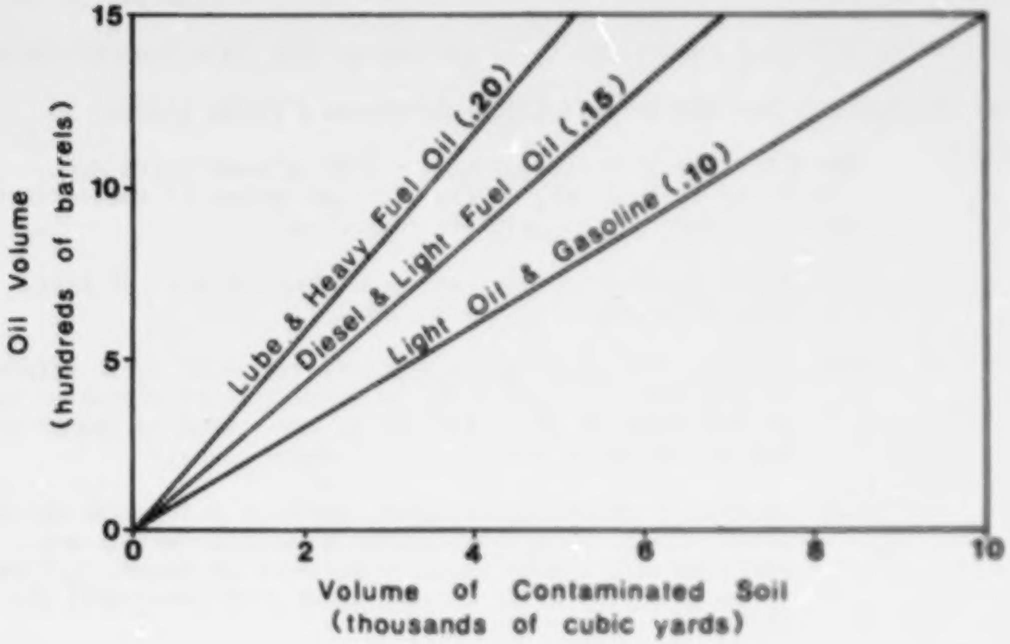
P = porosity of soil

SR = residual saturation

Two types of elements are present in sludge; those that dissolve in water and those which are suspended. When water comes in contact with sludge it is important to know what materials are dissolved or suspended. All sludge intended for land spreading in Illinois must have its supernatant analyzed in a leaching test for dissolved and suspended components.

Land spreading in Illinois at an enclosed disposal site, where runoff containing oil and heavy metals are confined, is allowed after the applicant demonstrates that the discharging surface water will meet effluent standards. The limiting volume of oily wastes to be land spread is 5000 gallons per acre per day applied in dry weather.[12]

Figure 3-1
Maximum Residual Saturation Curves



Oil	Maximum Residual Saturation
Lube and Heavy Fuel Oil	.20
Diesel and Light Fuel Oil	.15
Light Oil and Gasoline	.10

SOURCE: Reference 18

3.2.3 Deposition in Sewers

Oil dumped in sanitary sewers goes to the sewage treatment plant where it can upset the operation of the plant and be discharged to the receiving station. To prevent this, the Sewage and Waste Control Ordinance of the Metropolitan Sanitary District of Greater Chicago states:

> Any discharge of wastes or waters into a sewer which terminates in or is a part of the sewerage system of the sanitary district, must not contain the following:
>
> (a) Water or wastes containing more than 100 mg/l of fats, oils or greases (Hexane Solubles).
>
> (b) Liquids, solids or gases which by reason of their nature or quantity are sufficient to cause fire or explosion or be injurious in any other way to the sewage system or to the operation of the water reclamation plants.
>
> (c) Noxious or malodorous liquids, gases or substances which either singly or by interaction with other wastes are sufficient to create a public nuisance or hazard to life, to cause injury or to prevent entry into the sewers for their maintenance and repair.
>
> (d) Water or wastes containing toxic substances in quantities which are sufficient to interfere with the biological processes of the water reclamation plants.

Trace metals such as metal salts in metal cutting oils can also affect the operation of the sewage plant when metal ion concentrations exceed certain limits.[19] Metallic ion poisoning of the sewage plant in Lexington, Kentucky, on August 31, 1967, apparently caused by metal cutting oil, stopped the primary digesters from functioning.[20] Concentration limits are placed on any materials hazardous to the operation of the sewage facility. Some of these limits for the Metropolitan Sanitary District of Greater Chicago are given in Table 3-8.

The maximum concentration for fats, oils, or greases contained in sewage water allowed by the various sanitary districts throughout the

Table 3-8

Limits on Materials Hazardous to the Sanitary District of Greater Chicago

Waste Or Chemical	Concentration, mg/l
Boron	1.0
Chromium (Total)	25.0
Chromium (Hexavalent)	10.0
Copper	3.0
Cyanide (Total)	10.0
Cyanide (Readily Released at 150° and pH = 4.5)	2.0
Iron	50.0
Lead	0.5
Nickel	10.0
Temperature not over 150°F (65° C)	
pH	4.5 - 10.0
Zinc	15.0
Cadmium	2.0

Source: Reference 22

State of Illinois is 100 mg/l.[21] Sanitary districts outside the Chicago area appear to be relatively unconcerned with the heavy metal content of sewage waters because the major sources for these heavy metals, such as metal plating plants, are not usually present. There is, therefore, little chance that the local sewage treatment plant will be poisoned by metallic ions. The sanitary district of Springfield, Illinois, requires that the concentration of materials in the sewage water not exceed levels considered dangerous to the public, environment, or the operation of the sewage treatment facility, although no specific limits are delineated for the maximum concentrations of heavy metals.

3.2.4 Lagoon or Pond Storage

Lagooning or ponding is not a means of disposing of used oil. Rather it is a method for accumulating and storing the oil for a limited time. The inlet to the lagoon is usually baffled to collect floating oils and scums; any oil which escapes this baffle encounters a second baffle at the lagoon outlet. This trapped floating oil is sometimes ignited but is usually hauled away.

Many lagoons and ponds are large and are used mainly for the collection of sludge, which settles to the bottom. This sludge may have a high oil content. For example, sludge from lagoons of Marathon Oil Company at Robinson, Illinois (1969), was estimated to contain 35 percent oil.[14] The basin walls of these lagoons or ponds may consist of compacted soil, although lined basin walls are preferred because they are better able to prevent leakage. When a sufficient quantity of sludge is accumulated it is dredged out and hauled away.

The primary purpose of some lagoons is short-term oil storage. The influent to these lagoons contains minimal suspended solids. These lagoons are about 4 feet deep and designed for a 24-hour liquid retention time. Their basins should be lined to prevent oil leakage.

3.2.5 Deep Well Injection

The use of deep wells for disposing of hazardous industrial liquid waste is not extensively practiced in Illinois. Such wells must be located at a geologically acceptable site. The injection horizon, that is the area where waste is stored, should be composed of sandstones, limestones, or dolomitic rocks located well below the fresh water level. Immediately above and below the injection horizon, layers of clay, shale, or other impermeable material must be present to prevent escape of the liquid wastes (see Figure 3-2).

Deep injection wells are expensive (10 to 30 dollars per foot) and have limited storage capability. Due to the limited space, the deep wells should be reserved for materials more hazardous than oil and are not, therefore, recommended for oil disposal.

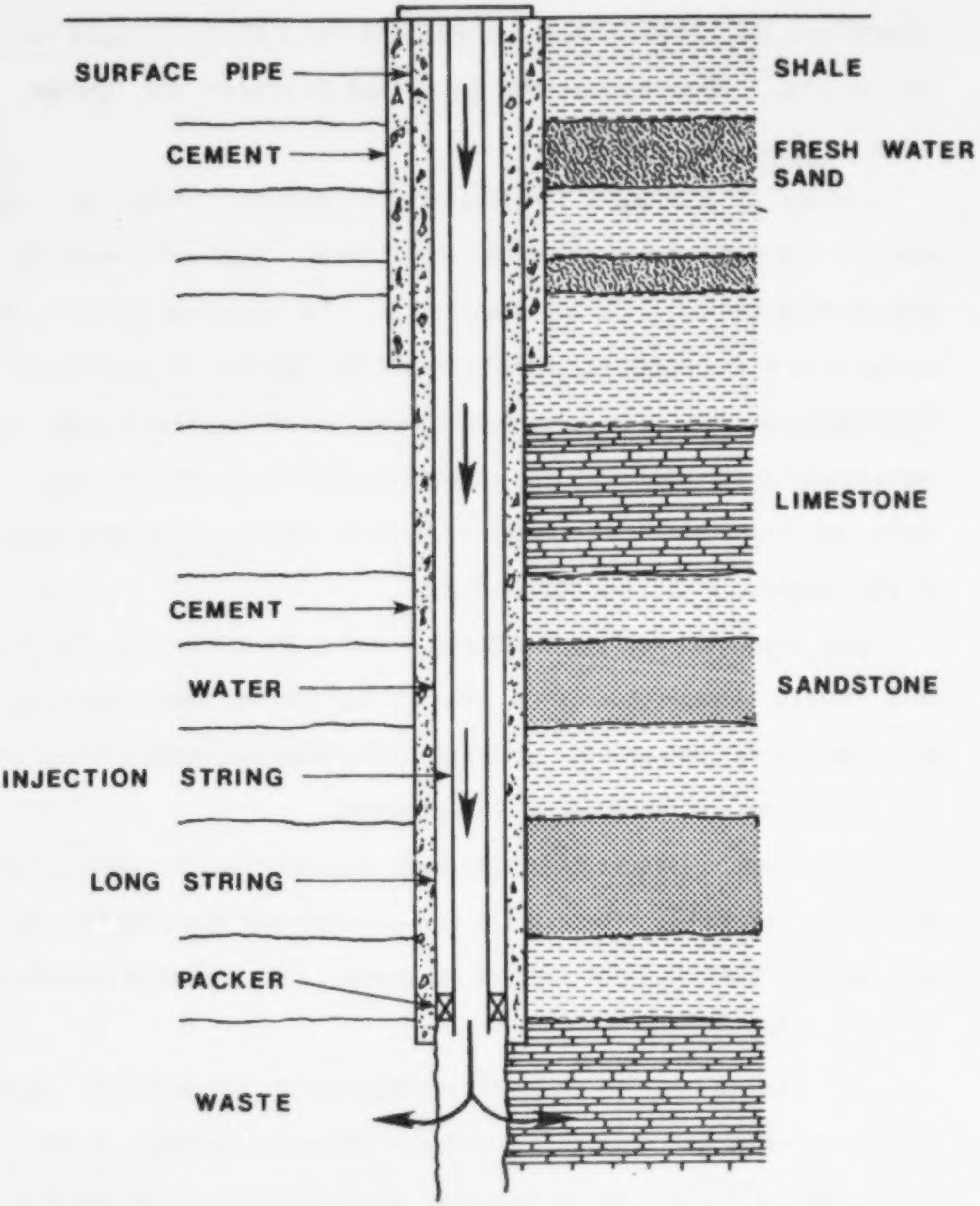
At present, Illinois has eight deep injection wells, seven of which are now in operation. These wells are used not for the disposal of used oil, but for toxic liquids such as wastewater that contains insecticides.

3.2.6 Incineration

Used oil may be thermally decomposed by incineration. Usually the incinerators are privately owned and centrally located. A few plants have sufficient waste that they have installed an incinerator on site. It is possible to recover the heat generated via incineration and

Figure 3-2

Schematic of a Deepwell


SURFACE PIPE
CEMENT
CEMENT
WATER
INJECTION STRING
LONG STRING
PACKER
WASTE
SHALE
FRESH WATER SAND
LIMESTONE
SANDSTONE

use it to heat the plant, produce hot water, etc. This results in a reduction in the quantity of fuel needed for these heating and process requirements.

There are 10 general methods of incineration:[23] Rotary Kiln, Multiple Hearth, Liquid Injection, Fluidized Bed, Molten Salt, Wet Oxidation, Plasma, Multiple Chamber, Gas Combustion, and Pyrolysis. Some of these methods can only be used for one phase of waste (solid, liquid, or gaseous); others may handle more than one phase.

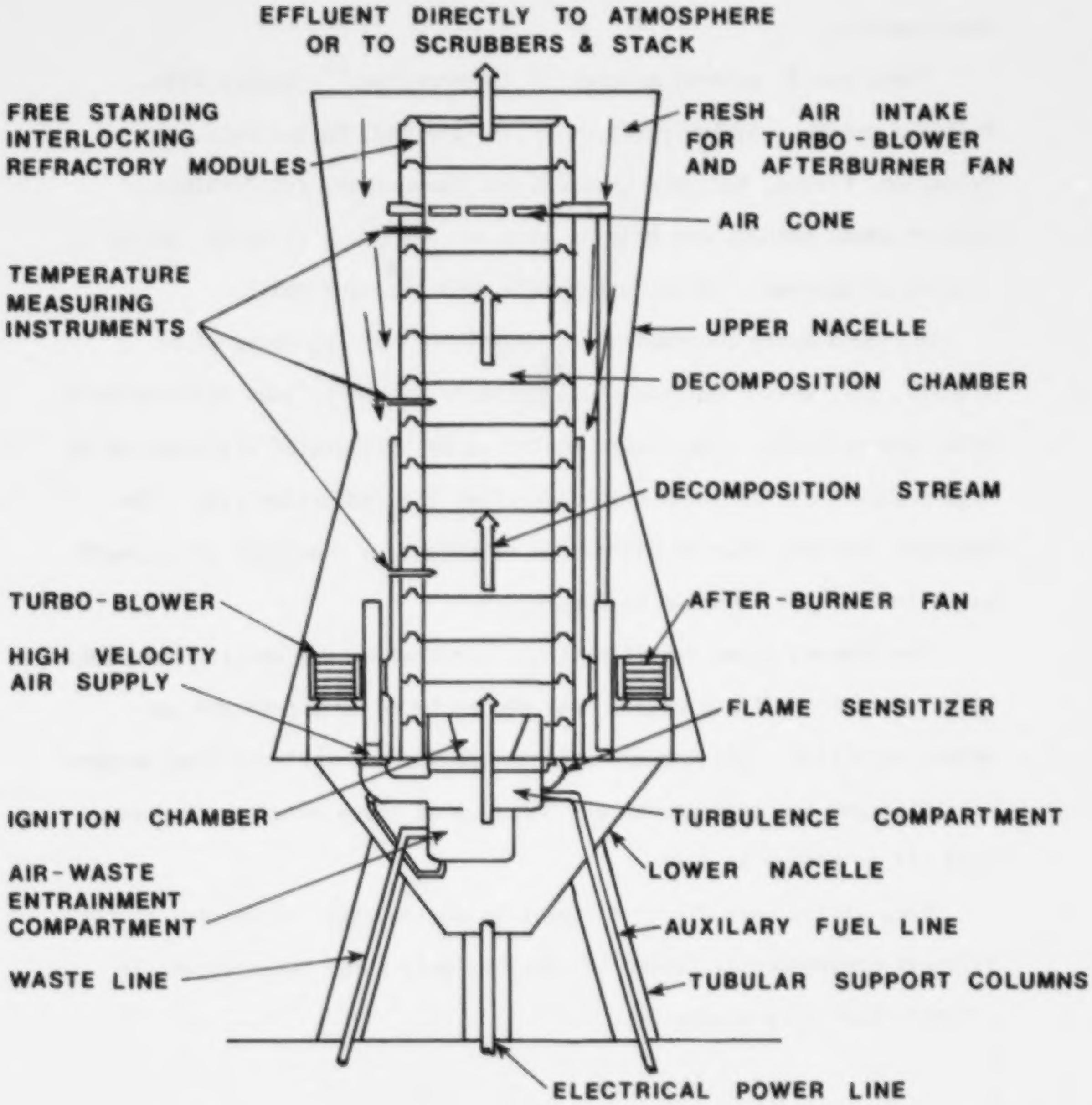
A Liquid Waste Incinerator is capable of burning among other liquids, oily waste, cutting oils, coolants, phenols, lube oils, soluble oils, and solvents. The liquid wastes to be incinerated are atomized by high pressure air or steam which increases the combustion rate. The droplets are less than 40 microns in diameter. A schematic of a Liquid Waste Incinerator is shown in Figure 3-3.

The exhaust gases resulting from incineration may contain hazardous materials such as trace metals that should be removed from the gas before expulsion. The contaminants in the gas and the resulting dangers to health and the environment are the same as those encountered when used oil is burned as fuel.

Very little used oil in Illinois is incinerated. According to the Illinois Environmental Protection Agency, only a few incinerators in Illinois burn oily sludge.

Figure 3-3

Schematic of a Liquid Waste Incinerator


EFFLUENT DIRECTLY TO ATMOSPHERE OR TO SCRUBBERS & STACK
FREE STANDING INTERLOCKING REFRACTORY MODULES
FRESH AIR INTAKE FOR TURBO-BLOWER AND AFTERBURNER FAN
AIR CONE
TEMPERATURE MEASURING INSTRUMENTS
UPPER NACELLE
DECOMPOSITION CHAMBER
DECOMPOSITION STREAM
TURBO-BLOWER
AFTER-BURNER FAN
HIGH VELOCITY AIR SUPPLY
FLAME SENSITIZER
IGNITION CHAMBER
TURBULENCE COMPARTMENT
LOWER NACELLE
AIR-WASTE ENTRAINMENT COMPARTMENT
AUXILARY FUEL LINE
WASTE LINE
TUBULAR SUPPORT COLUMNS
ELECTRICAL POWER LINE

Source: Reference 23

4.0 Organization of Illinois Oil Recovery Industry

A number of firms are involved in the recovery of industrial oil. The collection and transportation of used oils may be done by the generator of the oil or by professional oil collectors. Re-refining companies process the oil in order to restore it, if possible, to a state in which it is reusable for its original purpose. Reprocessors, on the other hand, generally reprocess in order to produce a usable fuel. Some oils are also reclaimed by treatment within the plant that generates it. The remainder of the chapter describes the organization and operation of these sectors.

4.1 The Collection of Used Oils

There are two basic types of used oil collectors--the contract collector and the gypsy collector. Of the first type of collector, a company with more than 10 trucks would be considered large. Generally, the contract or regular collectors own one or two trucks which they operate personally with the aid of one or two employees. These collectors have contracts with their industrial customers to empty and perhaps clean their storage tanks.

The second group, or gypsy collectors, are often drawn into the business by the possibility of large profits to be made by selling used oil as a fuel. Higher fuel prices and the increased marketability of used oil since the 1973 "energy crisis" have been causes for their entry into the collection business. Gypsy collectors lack stable market relations and long-term tacit or explicit agreements with the sources that generate or buy used oil.

Restrictions on the types of waste that a collector may normally handle might include those with low-flash-point materials and those containing toxic contaminants. A contractor may accept volatile materials by special arrangement.

When a collector uses a landfill for final disposal, there usually is no restriction on Bottom Sediment and Water (BS&W); however, if the oils are to be reprocessed, re-refined, or sold directly for fuel or other reuse, such as road oiling, then there may be a BS&W restriction. Most processors prefer that the BS&W be no more than 5-10% by volume of the used oil. The greater the BS&W content, the less valuable the used oil.

Depending on the nature and volume of the waste, collector cost may range from $.025 to $.125 per gallon. In the case of used oil where there are ready markets for a "good quality" high-volume oil, collectors might pay up to $.10 per gallon for the oil. A summary of used oil collector operating costs and revenues from sales is presented in Table 4-1.

In many cases, there will not be a buyer for used oil because of a high-percentage BS&W or other contamination. The disposal costs range from $.025 to $.04 per gallon for oily waste. Since a collector can increase his profit margin significantly by eliminating this cost, there is a great incentive for indiscriminate dumping. This dumping may occur in a rural field or a municipal sewer.

4.2 The Re-refining Industry

The number of re-refiners has decreased nationally from approximately 150 in the early sixties to less than 40 today. Re-refining production continued to increase until 1960, when it began to decrease. Table 4-2 lists production estimates from 1950 to 1975.

Table 4-1

Used Oil Collector Costs and Revenue in Illinois

RANGE OF TRANSPORTATION COSTS		LANDFILL DISPOSAL COSTS	COLLECTOR CHARGES/PAYS USED OIL SOURCE	SELLING PRICE FOR DIFFERENT USERS			
CENTS/GALLON							
<50 MILES	<200 MILES			ROAD OILING	RE-REFINING	REPROCESSING	FUEL DEALERS
.025 to $.03	$.0375 to $.05	$.025 to $.04	-$.10** to $.10*	$.05 to $.10	$.00 to $.10*	-$.03** to $.10* (rarely will bid up to $.12 to $.15)	WINTER $.12 to $.15 OTHER $.08

* Depends principally on BS&W content and volume. Upper limit of range generally means <2% BS&W.

**The collector or reprocessor normally will begin to charge for collection or processing where the BS&W exceeds 30%.

Source: Liquid Waste Control Association.

Table 4-2 Estimated Production of Re-refined Oil from 1950-1975

Year	Gallons of Oil
1950	50,000,000
1954	75,000,000
1960	300,000,000
1966	225,000,000
1971	120,000,000
1972	100,000,000
1975	49,000,000

SOURCES: Oil and Gas Journal, April 26, 1954 cited estimates for 1950 and 1954. Association of Petroleum Re-refiners provided production estimates for 1960-1971. The 1972 estimate source is the U.S. EPA. The 1975 figure is from Reference 2.

The decline in production in recent years can be attributed to several factors:

1. Processing difficulties and higher costs due to an increased additive package.
2. Federal Excise Tax Reduction Bill, 1965, which removed the $.06 per gallon excise tax from off-highway use oils.
3. The Federal Trade Commission ruling which required containers for re-refined oil to be labeled, "Made from previously used oil." This ruling, along with the Defense Department's refusal to use re-refined oil, increased the already difficult marketing problem.
4. Increasingly stringent environmental control regulations have made disposal of re-refining wastes difficult and costly.
5. The "Energy Crisis", beginning in the fall of 1973, increased fuel prices nearly threefold. This price increase diverted a

large percentage of collected oils to fuel use and uncontrolled burning in most cases. Cost of used oil feedstock to the re-refiner has increased as much as fivefold while virgin oil prices have risen by a factor of only 2.5.

6. The American Petroleum Institute (API) estimates that in some areas 40% of new automotive engine oil manufactured is purchased by "do-it-yourselfers" from retail stores. Little, if any, of the used oil available from this source is collected for any purpose.

Supply of Used Oil For Re-Refining

A steady supply of used oil is critical to the operation of the re-refiner. In many cases, re-refiners cannot operate at capacity for any length of time because of the variations in oil supply. Since most re-refiners depend principally on outside collectors for their oil, they must often outbid fuel oil dealers to obtain an adequate supply. But with the rapid increase in fuel oil prices, the re-refiner is at a severe disadvantage.

Several factors have influenced the supply of automotive engine oil. One factor is that a much larger number of people now change their own oil and then dispose of the used oil. Another factor is that automobiles require fewer oil changes. This effect has been offset to a small extent by the increase in total automobiles on the road.

Federal Tax Treatment of the Re-refining Industry

The excise tax on lubricating oil dates to the Revenue Act of 1932 when a 4-cent per gallon tax was levied on all grades of lubricating oils to be paid by the manufacturer or producer. This tax was increased by 1/2 cent in 1940 and an additional 1-1/2 cents in 1942, thus raising the total tax to 6 cents per gallon, which is the current tax. In practice, this tax has been applied only to virgin lube oil products. Re-refined oil has never been and is not taxed today. As a result, re-refined products made from 100 percent used oil enjoyed a 6-cent per gallon competitive advantage over virgin oil products until 1965.

The Excise Tax Reduction Act of 1965 removed Federal taxes on all lubricating oils, except those used in highway vehicles, and then earmarked this revenue for the Highway Trust Fund. The excise tax of 6 cents, still paid by the manufacturer and included in his price, was now applied only to automotive products; thus, off-highway users, such as industry, farmers, construction contractors and railroads, were made eligible for tax refunds. Because the primary markets for re-refined oil in 1965 were concentrated among consumers of industrial oils or off-highway users of automotive oils, the effect of this action was to equalize tax treatment of both virgin and re-refined oil in this market, and re-refiners lost their price advantage.

In theory, this lost price advantage could have been as high as 6 cents per gallon, provided that the re-refiner's product had been made from 100 percent used oil. However, most re-refiners manufacture blended products made from both used and virgin oil. Thus, in the case of a 50-50 blend, the re-refiner should have suffered a lost price advantage of only 3 cents per gallon, since the tax on the virgin component prior to the passage of the Act should have been passed through _pro rata_ as a cost of 3 cents.

In reality, however, the re-refiner who made a blended product was dealt an additional setback, for under IRS Ruling 68-108, unlike the virgin lube oil producer and his off-highway customer, the re-refiner and his off-highway customer were declared ineligible for the tax refund on the virgin oil component. Thus, in the case of the 50-50 blend, the combined result of the Excise Tax Reduction Act and the IRS Ruling 68-108 was to cause the re-refiner to absorb not a 3-cent, but a 6 cent market adjustment relative to his position prior to 1965. Since profit margins in this industry traditionally have been very narrow--on the order of 1 to 2 cents per gallon--these actions have been cited by re-refiners as a major cause of the decline of the industry.

FTC Labeling Requirement for Re-refined Oils

In 1964, the Federal Trade Commission, observing that the public has a preference for new oil and was therefore entitled to know the origin of its oil purchases, stipulated that re-refined oil products must be clearly labeled "made from previously used oil." Re-refiners contend that this particular wording unfairly implies inferior quality and that as a result of this ruling, many middlemen have stopped handling their products and that re-refined oil now competes directly with lower quality virgin oils.

The controversy over re-refined lube oil quality is on-going. In recent and separate tests by the Bureau of Mines and the Army Fuels and Lubricants Laboratory, some re-refined lube oil products failed to meet SE grade or MIL-L-2104C specifications; however, so have some virgin lube oils so advertised. The industry's reputation undoubtedly has been blemished by the questionable integrity of some operators who have not produced high-quality products. As a result, current Federal procurement regulations bar the purchase of re-refined oils, although the Defense Supply Agency is now developing a pilot program to experiment with recycled oils; the outcome of this program may lead to a change in this policy. FTC does not intend to make changes in its labeling requirements until this controversy over quality has been resolved.

Although the re-refining industry has suffered a number of setbacks (the loss of tax advantages, the barring of Federal markets, the labeling requirement, the quality controversy, the environmental questions over acid sludge disposal), it is nevertheless currently experiencing more demand for re-refined oil than it can supply, and its chief problem today is in obtaining sufficient feedstocks of used oil.

Re-refining Oil Quality Standards

The Energy Policy and Conservation Act of 1975 requires that the National Bureau of Standards (NBS) demonstrate both the equivalency of re-refined and virgin lubricating oils and develop simpler ways to measure the quality of lubricating oils. Quality for crankcase oils is now determined in what is known as automotive engine sequence tests. In these tests, the oil to be tested serves as a lubricating agent in an engine that is run through a specific sequence of operations for an extended period. The engine is then disassembled and checked for wear, corrosion, and so forth. These tests can cost as much as $20,000 for one oil sample, so re-refiners have had difficulty in demonstrating the quality of their products. This problem of demonstrating equivalency is compounded because many would say that since a re-refiner's used oil input varied in composition, tests would have to be run for each batch.

Establishing simple testing procedures and promulgating oil standards would eliminate many of the credibility problems that the re-refiner must now confront. The American Society of Petroleum Re-refiners (APR) hopes that this can be accomplished very soon.

Re-refining Economics

The cost for re-refining industrial lubes varies considerably. There are basically three considerations in determining what re-refiners will charge to re-refine a plant's used oil. First, the volume of oil that needs to be processed; second, how easily processable the used oil is or what the contaminants are and the quantities of each; and third, what types of oil the plant wants in return. The processability is generally determined by running a small quantity of oil sample through the re-refining process in the laboratory. The types of oil that a plant wants in return determines what additive package is needed and what degree of mixing with virgin lubes is required (for example, to adjust viscosity). A typical savings in the cost of re-refined versus virgin lubricants might be 20-25%.

4.3 Illinois Area Re-Refiners

There are two large re-refiners in the Illinois area whose products are regarded highly. Questionnaires were sent to both plants. Motor Oils Refinery in Lyons, Illinois, which is the largest re-refining company in the U.S., re-refines about 14 million gallons of oil annually, most of which comes from Illinois. The plant employs between 40 and 50 people and operates three shifts a day. Less than 30% of the oil that Motor Oils handles is industrial oil. The majority is railroad oil and the remainder is crankcase oil. The industrial oil is purchased from independent collectors. Almost all of Motor Oils' business is based on a closed-loop system in which an industry, fleet operator, or railroad sends its used oil to Motor Oils and receives credit toward the purchase of re-refined oil. This closed-loop re-refining service utilizes commercial haulers except in the case of railroads, which dump from tank cars directly into collection pits at the re-refinery. Motor Oils does not function as a collector itself.

Motor Oils also has been using and experimenting with a continuous vacuum distillation method in conjunction with the traditional acid-clay treatment. All of the used oil is being re-refined by this new process, for which Motor Oils has sought a patent. Table 4-3 presents a breakdown of the products produced by the Motor Oils Refining Company in 1976. The company has a well-equipped laboratory to test the used oil as it comes in, to examine its potential for re-refining and the price that will be paid to the waste hauler. The lab also tests re-refined samples to determine whether or not they meet required specifications.

Table 4-3 Types and Amounts of Re-refined Oil
Produced by the Motor Oils Refining Company (1976)

Product	Amount Produced in 1976 (thousands of gallons)
Lube & Hydraulic Oils	7,200 (mostly railroad oils)
Fuel Oil	2,600
Cutting Oils	800
Rolling Oils	350
Heat Treating Oils	20
TOTAL	10,970

In 1976, Motor Oils disposed of 3,925 tons of tank bottom and acid sludge waste at a landfill. This amount represents a 50% reduction from that disposed of in 1974. Another 3,456 tons of residuals were used in other products. It is expected that the amount of residuals will decrease to the point of eventual utilization of substantially all residues.

Oil-water separation, emulsion breaking, and skimming are used in waste water treatment at the plant. Air pollution control methods include stack effluent scrubbing and incineration. Most of the energy requirements for pollution abatement and plant operation are supplied by the re-refining process.

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Because of the increasing awareness of industry to conserve available supplies of lubricants and their desire to avoid pollution, more people are looking to the re-refiner. This fact in combination with Motor Oils' increased technological capabilities to process for reuse a broader spectrum of used oils and oily wastes, has meant a steady increase in business.

The other major re-refiner in the area is Westville Oil and Manufacturing Company, Westville, Indiana, located about 50 miles from the south side of Chicago. Westville Oil employs between 40 and 50 employees, working three shifts a day and process used oil according to the following state breakdown:

Illinois	10%
Indiana	70%
Michigan	10%
Ohio	5%
Wisconsin	5%

Westville Oil also functions as a used oil collector and collects oil from these sources, in the numbers shown:

SOURCE	NUMBER OF BUSINESSES
Service station and new car dealers	1000
Car and truck fleets	300
Railroads	2
Industrial plants	30
Other used oil collectors	10

In 1975, the plant produced about 2 million gallons of fuel oil, one million of which was used at the plant. The plant also produced 3 million gallongs of process oil, 3 million gallons of lube and hydraulic oils, and 1 million gallons of road oils.

Westville Oil uses the following processing methods: filtration, caustic, acid, clay, chemical treatments, and batch distillation.

About 50% of the tank bottom waste, acid sludge, spent clay, and distillation residues are subject to biological treatment at the plant; the other 50% is taken to a landfill. Waste water is treated by emulsion breaking, oil-water separation, and skimming. Scrubbers and bag filters are used for air pollution control.

4.4 Used Oil Processors in Illinois

Used oil processing differs from re-refining in that the oil is subjected to less treatment. The exact number of processors in the Illinois area is unknown. The Illinois Environmental Protection Agency has a list of six which it will provide to an interested company upon request.

All of the used oil processors also function as oil collectors. Their radius of service ranges from a few miles to, on special occasions, as far as California. Most of them process oil from several neighboring states. The average firm has three to four trucks with a total capacity of from 10,000 to 15,000 gallons. The average plant employs eight people. The most common types of processing include settling, filtration, centrifugation, chemical, acid and clay treatment, and batch distillation. Almost all of the oil product produced is used for fuel oil (some is used for coal spraying), although some of the oil is used for dust control and road oiling. Smaller amounts of industrial lubes and railroad oils are produced. Very little quantitative data in this area appeared on the questionnaire responses.

Processing wastes are generally taken to the landfill, although one respondent listed deep well disposal.

The quantities of used oil reprocessed in Illinois as given in the processors survey are presented in Table 4-4.

Table 4-4 Quantities of Oil Reprocessed in Illinois

Questionnaire Number	Oil Processed in Illinois (million gallons)	Industrial	Crankcase & Other
1	2	0.7	1.3
2	6	*	
3	1	*	
4	1.2	0.6	0.6
5 (representing 5 plants)	4.2	1.7	2.5
Total	14.4		

* Breakdown not given

The total value of oil processed could perhaps be increased by 20% to include those smaller oil processing companies which are not represented in the survey. The total from the nine plants is 54.5 million liters. If this value is increased by 20%, one obtains approximately 64.4 million liters of oil being processed in the State of Illinois.

Most companies were optimistic about their future and saw continued growth. Increasing fuel prices mean that less of the oil is going for road oiling, etc. and more for use as a fuel, either as a virgin oil supplement or for coal spraying. Higher prices for fuels also works against the processor, since many more large industries are using their own used oil as a supplemental fuel supply.

4.5 Reclaiming Used Oil Within the Plant

The increasing price of industrial lubricants and fuel oil, combined with some limited degree of environmental accounting of waste, has caused Illinois industry to greatly increase the reuse of used oil within the plant. Many larger industrial plants have already significantly reduced the quantities of lubricants purchased. Plant management has realized that by reducing the amounts of oil waste requiring disposal, they can reduce waste collection costs and water treatment facility costs.

Used industrial lubricants at the storage point are composed of many different oils and foreign materials. These oils from the metal and metal-working industries will include: hydraulic oils, greases, quench oils, gear lubricants, slide and way lubricants, spindle oil, straight cutting oils, emulsifiable cutting oils, rustproofing oils, drawing oils and compounds, and forging oils and compounds. Other materials found in the oil stream are water, solvents, solvent and alkaline cleaners; a wide variety of soaps, emulsifiers, detergents and dispersants, additives to control oxidation and corrosion, and solids such as graphite and mica; and to further complicate cleaning for reuse or disposal, cloth, paper, plastics, and other trash enters the stream.

Of course, the many problems that a plant encounters in handling used oil can be reduced by minimizing oil usage. Below are listed several methods for reducing total oil usage in the plant.

1. Maintenance and housekeeping.

    Large quantities of oil become waste through leakage, overflow, and overspray. The greatest source of oil loss is in hydraulic systems. Better sealing and maintenance of the hydraulic equipment can greatly reduce this loss. The loss from overspray of cutting oils and coolants can be substantial and also present safety hazards.

2. Increasing the life of machining fluids and lubricants.

   Often the life of circulating coolants or lubricants that have been contaminated by solids, sludge, and bacteria can be extended. Adequate maintenance of these systems with skimmers to remove so-called tramp oil, centrifuge, and filters to remove water and solids, and bactericides can prolong use and thereby reduce the quantities of virgin oil needed and the amount of waste material.

3. Substitution of biodegradable materials for non-biodegradable.

   Assuming that the coolant or cleaner does not become too contaminated with non-biodegradable material, direct disposal to a sanitary sewer is possible.

4. Reuse of the oil.

   An oil (for example, a quench oil) can be reused in another operation, such as machining, forging, or rustproofing.

The major problem encountered in setting up a reclamation program within the plant or reprocessing or re-refining outside the plant is that of segregation of oil and water streams. The treatment processes required could be greatly simplified if oils of different types, such as, hydraulic oils and emulsifiable oils could be collected separately, and if the percentage of water could be minimized. In some cases the oil is washed down the floor drain with water hoses. This practice results in varying water contents in the used oil and if this waste is simply collected in a tank for a waste hauler, the mixture will probably be worthless and would involve disposal costs as well. In most cases, if the water and perhaps certain oils and solvents were collected separately, the used oils might cost-effectively be reclaimed within the plant, sent to an outside processor, or relatively easily cleaned for supplemental fuel use. Separation of the waste streams also would insure more efficient operation of waste water treatment plants.

Some of the principal reasons for collection of oil and water in a single tank include simplicity, lack of space for additional containers, and the costs for the plumbing that would be required to separate the oil and waste streams.

The cost savings realized in reducing the amount of lubricants purchased plus the virgin fuel savings can often justify radical plumbing changes. Appendix III presents a case study for five industrial plant oil paths.

5.0 Recycling and Re-refining Technologies

Since the vast majority of oil is not consumed or chemically changed while performing its intended function, it could be reused after undergoing varying degrees of cleansing. The oil can be re-refined into good lubricating oil or used as a feedstock in the manufacture of other petroleum products. In many cases, the oil can often be reclaimed to nearly original quality, significantly prolonging useful oil life. Often this can be done within the industrial plant itself. The oil also can be reprocessed to clean fuel oil and, under special conditions, can be burned safely untreated.

Recycling processes remove unwanted contaminants to produce useful products. Used oils will generally contain sludge, water, and varying concentrations of heavy metals and other substances which may have entered the oil through use or may originally have been oil additives. An example of the last case is the organic sulfides which frequently are added to oil to inhibit oxidation.

Recycling consists of either reclaiming used oil or the more thorough processes of reprocessing and re-refining. Some well-segregated industrial oils may be recycled through reclaiming, which removes only solids, water, and perhaps, small percentages of other materials, such as products of oxidation.

Reclaiming is a process which employs one or more of the following physical processes:

Use of Heat (150°F-200°F)
Gravity settling
Centrifugation
Vibrating screening of solids
Use of Surfactants (e.g., demulsifiers)
Dehydration
Filtration

Reprocessing involves the same pretreatment elements as reclaiming, but in addition, acids, alkalis, amines, and/or solvents may be used to remove materials such as water and solids. Reprocessing of oils may produce clean fuels, form oils, certain lubricants, and possibly process oils.

Re-refining--the most thorough recycling process--may employ distillation and steam stripping of pretreated oils, usually with activated bleaching clay, in addition to the physical and mechanical processes involved in reclaiming and the chemical additives involved in reprocessing. This process removes light ends and remnants of contaminants not removed in pretreatment. In general, re-refining means the application of processes which not only use gravity, heat, and physical separation techniques such as filtering, centrifuging, and dehydrating (reclaiming), but proceed further through the application of distillation, fractionation, and/or chemical processes to recover the oils for reuse. Re-refining produces fuel (distillate) and lubricating oil base stocks which can be used for motor oils, transmission fluids, gear oils, cutting oils, hydraulic oils, quench oils, and many others.

The remainder of this chapter is a review of some of the major recycling and re-refining processes in use or currently under development. These processes include:

Acid Clay Process
Distillation/Clay Treatment
Meinken Process
ERDA Re-refining Process
Exxon Process

The first three of these are in widespread use. Commercialized recycling technology applications are generally more advanced in Europe than in the United States. The ERDA process, Exxon process and a number of others are, however, presently in development or demonstration stages in the U.S.

5.1 The Acid/Clay Process

The flow scheme of a typical acid/clay process is shown in Figure 5-1. The process has traditionally been the workhorse of the re-refining industry. However, studies have indicated that most recycled lubricating oils have been overtreated to the extent that they have lost a great deal of their lubricating qualities. Re-refiners long ago abandoned treating virgin oil with sulfuric acid because of inefficiency and waste. Yet many plants in the U.S. still use this method.

5.2 Distillation/Clay Treatment[3]

There are several variations of the distillation/clay re-refining treatment. Figure 5-2 is a basic flow diagram of the process, with a broken line dividing it into the pretreatment and distillation steps. The amount of process waste is greatly reduced, whereas with the acid/clay process large amounts of acid sludge are produced, which presents a serious disposal problem.

The process first dehydrates the oil in a flash tower by heating to 300°F. The lighter oil/water in the upper layer is condensed and sent on to an oil decanter. There the water phase is separated and removed to the wastewater disposal system, and the oil layer is directed to a storage tank for future use as fuel.

The heavier oil in the bottom of the flash tower is passed through a heat exchanger to reduce the temperature to approximately 100°F.

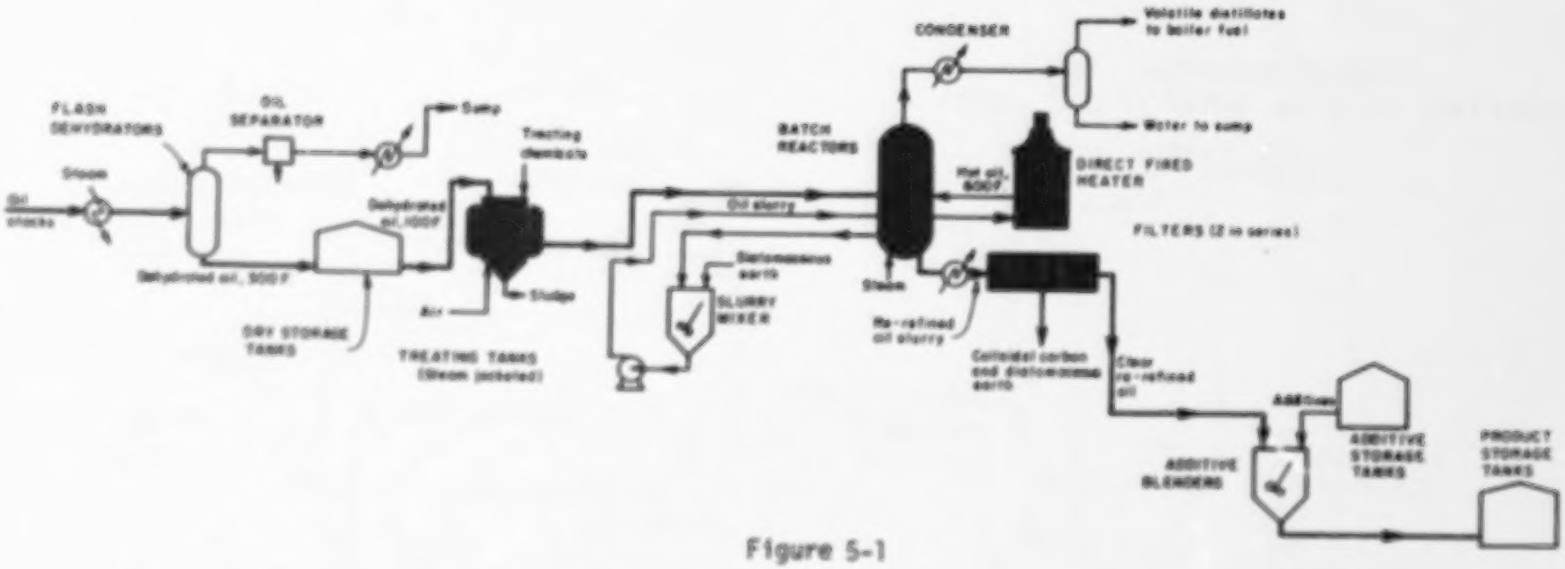
FLASH DEHYDRATORS
Oil stocks
Steam
OIL SEPARATOR
Sump
Dehydrated oil, 300°F
DRY STORAGE TANKS
Dehydrated oil, 100°F
Treating chemicals
Air
Sludge
TREATING TANKS (Steam jacketed)
Oil slurry
Diatomaceous earth
SLURRY MIXER
BATCH REACTORS
Steam
CONDENSER
Volatile distillates to boiler fuel
Water to sump
Hot oil, 600°F
DIRECT FIRED HEATER
FILTERS (2 in series)
Re-refined oil slurry
Colloidal carbon and diatomaceous earth
Clear re-refined oil
Additives
ADDITIVE STORAGE TANKS
ADDITIVE BLENDERS
PRODUCT STORAGE TANKS

Figure 5-1

Flow Scheme of Acid Extraction Type Re-Refinery

Source: Reference 14

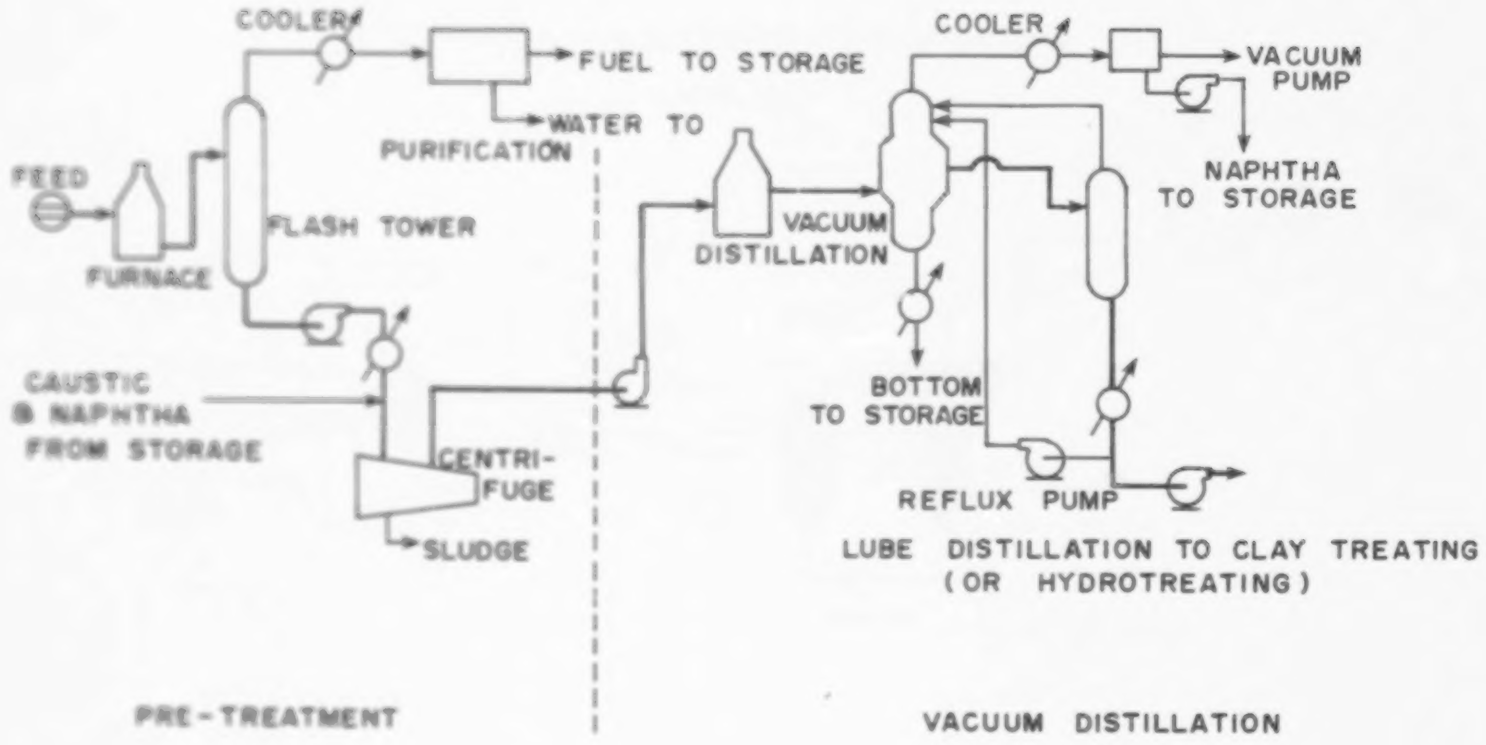
COOLER
FUEL TO STORAGE
WATER TO PURIFICATION
FEED
FURNACE
FLASH TOWER
CAUSTIC & NAPHTHA FROM STORAGE
CENTRI-FUGE
SLUDGE
VACUUM DISTILLATION
COOLER
VACUUM PUMP
NAPHTHA TO STORAGE
BOTTOM TO STORAGE
REFLUX PUMP
LUBE DISTILLATION TO CLAY TREATING (OR HYDROTREATING)
PRE-TREATMENT
VACUUM DISTILLATION

Figure 5-2

Vacuum Distillation of Crankcase Oil

Source: Reference 3

Light oil, having a boiling range of 150-250°F is introduced into the dehydrated oil stream. The quantity used is approximately 20% based on oil volume. A small amount of caustics (0.2-2.0%, depending on feedstock emulsions) is also introduced. The addition of the light oil and caustics tends to break the oil-water emulsion and precipitate solids. These materials are then removed by centrifugation. The sludge from the centrifuge can be disposed of separately, e.g., by landfill, or it can be mixed with the distillate bottom layer as described later.

The naphtha/caustics/centrifuge pretreatment step may not be a necessary adjunct to distillation, but it does tend to eliminate some of the materials which can cause fouling and erosion in the vacuum distillation furnace and column, and associated heat exchangers.

The centrifuged oil is then pumped to the vacuum distillation tower through a direct fired heater. The furnace heats the oil to about 700°F. The column operates at a vacuum of 27 inches of mercury. The overhead naphtha, with a boiling range as shown in Table 5-1, is condensed, cooled, and used as fuel in the plant. The distillate bottom layer, which contains almost the entire ash content of the feed, is cooled and used as fuel or for blending into asphaltic products, or is stored in a lagoon. One or more middle distillate cuts are taken (Table 5-1) and sent on for clay treatment for finishing as a lube blending stock.

The clay treatment is similar to that described for the acid/clay process except that prior stripping is unnecessary and the clay quantity may be reduced to as little as 0.125 lbs. per gallon of oil. The filter cake obtained during filtration is disposed of in the usual manner.

Table 5-1

Physical Properties of Vacuum Distillation Fractions[36]

Fraction	Name	Amount, % of Feed	Color	Viscosity SSU	Boiling Range °F	Specific Gravity	Flash Pt. (Open Cup) °F
1	Naphtha	1.5			145-446	0.7972 46° API	
2	Barometric	9	4 1/2	33-340 100°F	400-680	0.8602 33° API	
3	Light Side-stream	36	8	100 @ 100°F 39.1 @ 210°F	680-792	0.8735 30.5° API	350
4	Heavy Side-stream	28	8	222 @ 100°F 47.6 @ 210°F	792-900	0.8789 29.5° API	430
5	Bottoms	22	Dark	284 Sayb. Furol @ 122°F	900+	0.9937 10.9° API	
Residue, Water + Loss		3.5				1.0 10° API	
		Total 100%				Av. S.G. of Feed Stock 0.9035 25.1° API	

* No pretreatment

The yields for this type of operation, based on input oil, are approximately 70%, comparable to the best acid/clay treating operations. Product quality should also be comparable, although viscosity at 210°F seems to be somewhat lower due to bottoms removal.

By taking more than one side-stream from the vacuum distillation column, it may be possible to obtain a part of the yield as higher viscosity lube stocks. It is believed that clay treatment leaves most of the lube properties relatively unchanged, except for improvements in color, neutralization number, and reductions in oxygen and nitrogen content.

Odor and wastewater problems are not believed to be any more serious with this process than with acid/clay treatment. However, when a barometric condenser is used for the vacuum column, the quantity of contaminated wastewater is very large. Water- or air-cooled surface condensers are preferable to barometric condensers, but are more expensive; however, the increased cost must be balanced against the decreased cost of waste-water treatment.

5.3 Meinken Process

5.3.1 Description of the Plant for the Production of Lubricants from Used Oil (Figure 5-3)

The Meinken Process is capable of reliably dehydrating used oil with a water content of more than 20% without excessive heating (above 160°C). This and other advantages of the Meinken Process are responsible for its being employed by 30 European firms to dehydrate used oil.

The used oil is taken by tanker or in barrels to the refinery. Here it is passed through a coarse filter causing fibers and other impurities

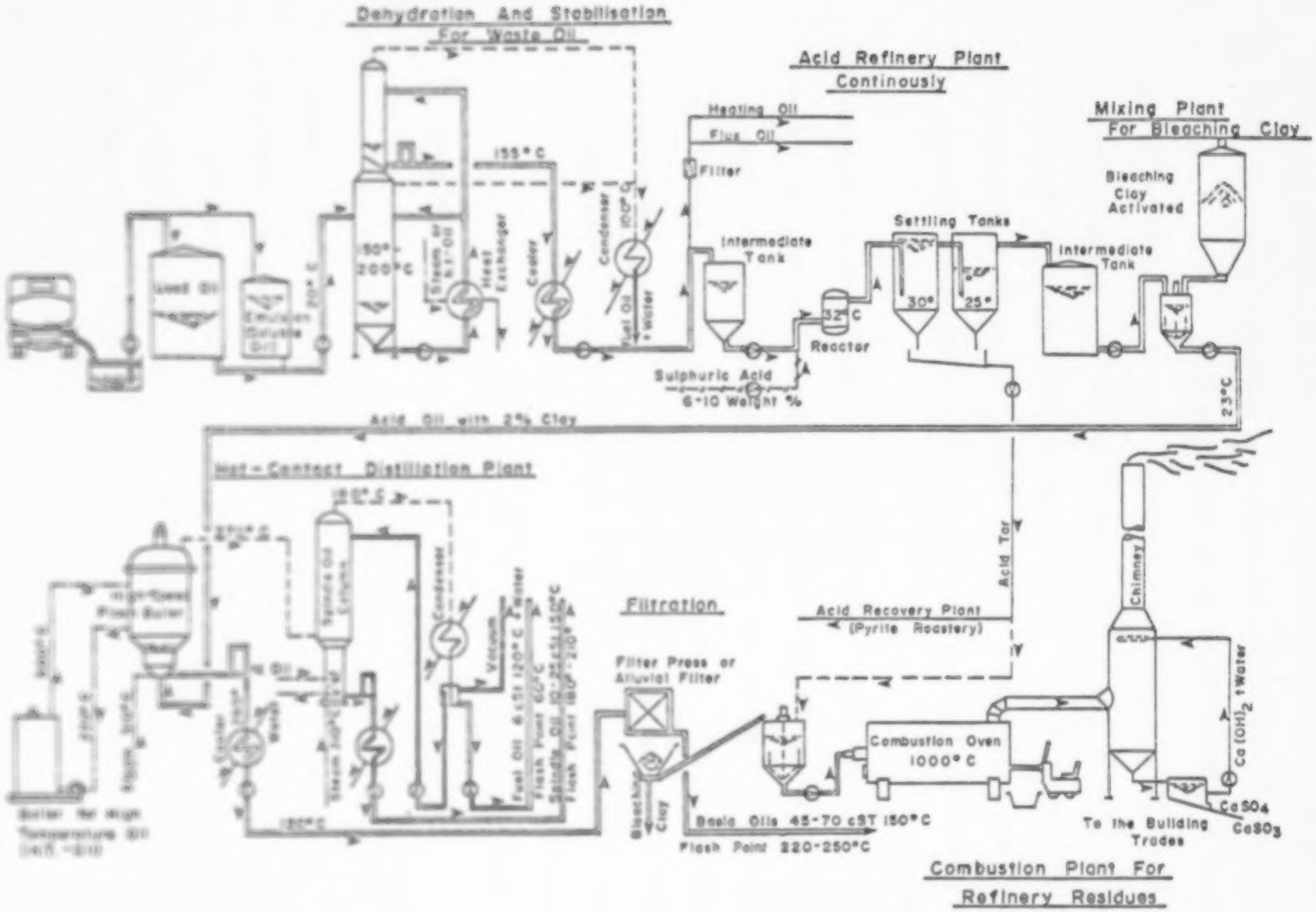
Dehydration And Stabilisation
For Waste Oil
Used Oil
Emulsion Soluble Oil
20° C
190°-200°C
Steam or H.T-Oil
Heat Exchanger
155° C
Cooler
Condenser
100° C
Fuel Oil
+ Water
Acid Refinery Plant
Continously
Heating Oil
Flux Oil
Filter
Intermediate Tank
Sulphuric Acid
6-10 Weight %
32° C
Reactor
Settling Tanks
30°
25°
Intermediate Tank
Mixing Plant
For Bleaching Clay
Bleaching Clay Activated
23°C
Acid Oil with 2% Clay
Hot-Contact Distillation Plant
High-Speed Flash Boiler
Spindle Oil Column
Condenser
Vacuum
Water
Cooler
Steam
Fuel Oil 6 cSt 120° C
Flash Point 60°C
Spindle Oil 10-25 cSt 150°C
Flash Point 180°-210°
Boiler for High Temperature Oil
Filtration
Filter Press or Alluvial Filter
Bleaching Clay
Basic Oils 45-70 cST 150°C
Flash Point 220-250°C
Acid Tar
Acid Recovery Plant
(Pyrite Roastery)
Combustion Oven
1000° C
Chimney
$Ca(OH)_2$ + Water
$CaSO_4$
$CaSO_3$
To the Building Trades
Combustion Plant For
Refinery Residues

Figure 5-3 The Meinken Used Oil Regeneration System

larger than 3 mm-grain size to be separated from the oil. It is then stored in receiving tanks.

Thermic dehydration of the used oil is the first stage in the regeneration process and occurs under conditions of normal pressure and a temperature of about 160°C. The used oil is heated by means of a heat exchanger and continually circulates from the lower column of the dehydrating plant, containing the circulation pump, through the heat exchanger and back into the lower column of the dehydrating plant. Heat from thermic dehydration is provided by steam or high temperature oil.

Circulation of the used oil through the heat exchanger is of considerable importance to the dehydrating plant because it ensures the following conditions:

1. The heat exchanger remains free of deposits.
2. The high flow rate inside the heat exchanger produces a good coefficient of heat transition.
3. Decomposition of the used oil is not possible.

During circulation, some of the used oil is automatically removed and transferred into the upper, second column stage where residual dehydration of the used oil takes place. The dehydrating plant is therefore a two-stage column, in which the two stages operate independently from one another. This arrangement makes it possible to reliably dehydrate used oil of a high-water content (above 20%) without having to raise the temperature.

The evaporated water with the light hydrocarbon (boiling up to 160°C at normal pressure) condenses in the water-cooled condenser of the plant.

The dehydrated oil flows from the upper column stage through a cooler, where it is cooled down to approximately 32-40°C by means of water, then into the intermediate tank for dehydrated oil. The cooling water is produced in a water cooling tower.

The entire dehydration plant can be started within 45 minutes, and reaches its full throughput capacity after this time. The time taken for switching the entire plant off is 15 minutes; i.e., the dehydrating plant can be switched on daily and be switched off at any time, as required. After switching the plant on, it runs automatically; the only requirement is that the instruments be checked from time to time.

As soon as the dehydrated used oil tank is filled to half its capacity, the sulfuric acid refining plant is switched on automatically. The sulfuric acid refinery comprises a central reactor of the "Fiscalin" system (international patents) with a dosing pump for dehydrated mineral oil and a dosing pump for sulfuric acid. In addition, 3 settling tanks, 1 intermediate tank for refined used oil (acid oil), 1 storage tank for acid tar, 1 pump for acid tar, and control and measuring instruments are required. After flowing through the reactor tank, the acidified mineral oil passes through the 3 settling tanks with a dwell time of approximately 24 hours. The acid tar (refining residue) is sluiced continuously from the 3 settling tanks as soon as a predetermined acid tar volume has been reached. Sulfuric acid refining takes place at a temperature of approximately 30°C. The refined acid mineral oil flows continuously from the last decanting tank into another tank, where it is mixed with activated bleaching clay. An alternative is provided here in the form of an intermediate tank upstream of the mixing agitator. Automation is such that upon exceeding a specified level in a decanting tank, the reactor apparatus or even the dehydrating plant can be switched over to idling for a brief period until the plant has stabilized itself.

When the bleaching clay is mixed with the acid mineral oil, an infinitely variable dosing pump moves the oil/bleaching clay mixture into a flash boiler. This flash boiler is heated by means of high-temperature oil, which constantly circulates between furnace and flash boiler. This part of the plant is called "hot-contact distillation plant". The volatile components of the used oil flow in the form of vapor into the adjacent spindle oil column, and from there into the condenser, where all vapors are completely condensed.

The distilled mineral oil which still contains the bleaching clay flows continously from the flash boiler through a water-cooled heat exchanger to a filter press, or an alluvial filter.

The hot-contact distillation plant operates under a vacuum of approximately 80 mm Hg. The vacuum is produced by a steam jet gas exhauster, or by a piston valve gas pump (piston vacuum pump). This kind of vacuum production has the advantage that no water (wastewater) is obtained when creating the vacuum.

The waste gases in the vacuum-producing plant are burned in either the steam boiler or the furnace where the production of overheated steam occurs. Overheated steam is blown into the flash boiler and into the spindle oil column to reduce the partial oil pressure inside the plant to 8 mm Hg. In addition, the oil is deodorized.

The advantage of the hot-contact distillation plant is that it can be switched on or off at any time without affecting the oil quality.

After switching on, it takes 60 minutes before full production is reached. The maximum switching-off period is 30 minutes.

Since the plant is heated by means of heat carrier oil, cracking of the oil is absolutely impossible. Therefore, far less bleaching clay is needed than with any other system known today.

The oil produced is quite stable with regards to its color and its resistance to aging. The produced mineral oil is generally emulsion-proof, and the viscosity of the base oil can be adjusted to the desired value.

In the production of spindle oil, a valve bell-equipped column is used and operated with a relatively high return flow. The cooling water for the hot-contact distillation plant is obtained from a water cooling tower.

To prevent corrosion in the condenser tubes, ammonia is injected upstream of the condenser, and a corrosion inhibitor added. All parts of the plant where corrosion may set in are given a coating of phenolic resin, which is stable up to +180°C, and provides almost absolute protection against corrosion.

No control is required once the plant has been switched on. All measurements are relayed to a small control center where they are also recorded.

All mineral oils flowing out of the hot contact distillation plant are filtered in a filtration plant. The filtering is done using a settling filter as this facilitates the manual work (cleaning of the filter, etc.). The waste products of the used oil are:

1. Process wastewater, approximately 130 kg/1000 kg used oil
2. Process waste gases, approximately 40 Nm^3/1000 kg used oil
3. Acid tar, approximately 150 kg/1000 kg used oil
4. Oleiferous active earth, approximately 20 kg/1000 kg used oil.

These are explained further below:

1. One kilogram of the process wastewater contains approximately 200 mg of emulsified oil and 30-80 mg of phenol. Because the removal of the phenol presents considerable difficulty, the wastewater is evaporated in an evaporator with direct flame contact and subsequently is passed into a combustion furnace. The furnace atmosphere has a temperature of 1000°C so that all oil and phenol components are burned out of the water vapor introduced.
2. The process waste gases are simultaneously introduced into this furnace and burned. This method of eliminating the waste water and waste gases has been recognized as satisfactory by the West German environmental protection authorities. For this purpose, heating energy is required, that is to say approximately 20 kg of fuel oil per 1000 kg of used oil. If a combustion furnace for acid tars is available, the wastewater and waste gases can be burned in this furnace eliminating the need for another furnace.
3. The acid tar and the oleiferous active earth are burnt in a stationary furnace. These waste products are introduced into this furnace satisfactorily by the acid tars. The resultant hot flue gases (t = 1000°C) can be utilized for production of

steam or cooled down to 350°C by the addition of cooling air. Dust is extracted from the waste gases by cyclones which reduce the dust content from approximately 2.1 g/Nm^3 to 0.15 g/Nm^3.

The best solution for elimination of the acid tars is not combustion, but conversion or use of the acid tars as basic material for another industry.

Two examples of this are described below.

In Sweden, the acid tars are neutralized with caustic soda (NaOH 50%) and these neutralized tars are supplied to a sulphate factory where they are burnt with the black lye from wood cellulose production. From the Na_2SO_4 which is formed during the neutralization of the tars, Na_2S is formed and is used again in the cellulose boiling plant.

Another alternative is to supply the acid tars to a pyrites roasting plant for the production of sulfuric acid. This alternative has been used for many years in West Germany.

5.3.2 Description of the Plant for Production of Fuel or Flux Oil from Used Oil (Figure 5-4)

In industry today considerable quantities of used oil occur which can no longer be regenerated or where regeneration is not economical.

Primarily, these are oils from the steelhardening shops, cutting oils from mechanical engineering works, mineral oils with special synthetic additives, certain mineral oils from gear transmissions, grease-loaded oils, etc. These oils in some cases contain 70-90% water and form a stable emulsion with the water.

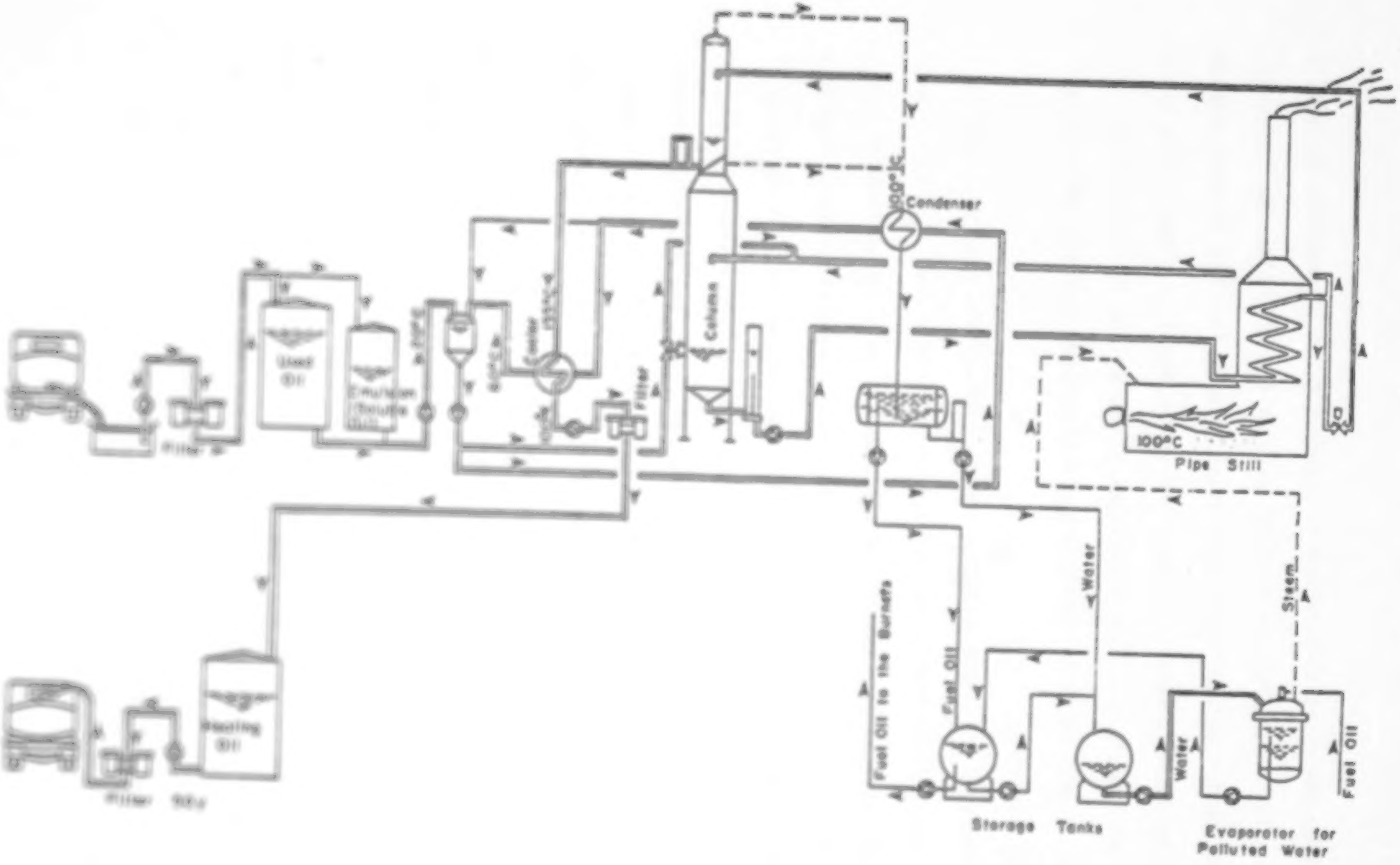
Used Oil
Emulsion (Soluble Oil)
Filter
Cooler
Filter
Column
100°C
Condenser
100°C
Pipe Still
Fuel Oil to the Burners
Fuel Oil
Water
Water
Steam
Fuel Oil
Storage Tanks
Evaporator for Polluted Water
Heating Oil
Filter

Figure 5-4 The Meinken Process for Producing Fuel Oil from Used Oil

With the plant illustrated in Figure 5-4, it is possible to treat all these oils to form fuel or flux oil and, at the same time, to eliminate the wastewater and the small quantities of dirt from the filters without installation of a water treatment and an incineration plant. This plant has been recognized by the environmental protection authorities in Sweden as well as in Switzerland and West Germany and many such units are in operation.

The fuel oil produced still contains 60% of the used oil metal additives. It is therefore advisable to mix these fuel oils with commercial fuel oil in a proportion of 10-20%. The plant can be operated under vacuum at a temperature of 160-260°C. The oils produced then have a high flashpoint (appoximately 230°C) and are suitable as additives for the production of road bitumen etc. (flux oil). In West Germany a large proportion of these oils is consumed by the bitumen manufacturers.

The used oil containing approximately 10% water and the oil emulsions with approximately 80-90% water are stored in separate containers.

A pump conveys the oil through two reversible filters into the charging tanks. From here, a charging pump draws off the used oil to be processed -- if required, a certain proportion of oil emulsion can be added to the used oil -- and passes it to a holding tank. A circulation pump circulates the used oil through a condenser and to the outlet cooler, then back into the holding tank. When circulated, the cold used oil assumes a temperature of 80°C as a result of the heat exchange. A float valve in the bottom section of the column supplies old oil as required and, at the same time, maintains the required level in the column.

An additional circulation pump forces the old oil through a pipestill back into the column. As soon as the required operating temperature (155°C) is reached an electronically controlled motor valve opens and a part flow of the partially de-gassed used oil rises into the top column section for final de-gassing.

The dehydrated used oil emerges continuously from the top column and is cooled down to approximately 100°C in the outlet cooler and is pumped through a self-purifying filter (100-200 My) into a storage tank by means of a centrifugal pump. When the fuel oil (dehydrated used oil) is transferred, the oil is filtered one last time.

The water and light oil vapors occurring during dehydration are condensed and cooled with undehydrated used oil in a condenser. The light oil (gas oil) and the water are conveyed to storage tanks by means of two centrifugal pumps. The gas oil is used as fuel oil for heating the pipestill and the wastewater evaporator.

The wastewater is continuously evaporated in an evaporator by the direct action of an immersed oil flame. The resultant steam is passed into the antechamber of the pipestill and heated to approximately 1000°C. At this temperature the traces of phenol and oil from the steam of the water evaporator are burned off.

The whole plant functions fully automatically. It requires a start-up time of 45 minutes and a shut-down time of 15 minutes. Typical analyses of re-refined oils from the Meinken process are presented in Table 5-2.

Table 5-2

Typical analysis of Re-refined oil from a "Meinken" Plant System

1. Basic oil

Specific weight at 15.6°C/60°F	0.899 kg/l
Flash point in open crucible C.O.C.	249°C/480°F
Thickening point:	-20°C/-4°F
Viscosity at 50°C:	56.1cSt/7.42°E 260 SSU/100°F
Viscosity index:	94...96
Neutralization figure:	0.02 mg KOH/g oil
Conradson test:	0.13%
Ash oxyd:	0.005%
Color per ASTM:	2.5...3.0
Bleaching earth consumption TONSIL L 80:	2.5%
Sulfuric acid consumption 96%:	8%
Emulsions characteristics at 130°F after 22 min.	37-40-3
Emulsions characteristics at ASTM D1401 after 25 min.	40-40-0
37-40-3 means	37 ml oil phase 40 ml water phase 3 ml emulsion
40-40-0 means	40 ml oil phase 40 ml water phase 0 ml emulsion

2. Spindle oil

Specific weight at 15.6°C/60°F:	0.880kg/l
Flash point in open crucible C.O.C.:	215°C/419°F
Thickening point:	-14°C/+6.8°F
Viscosity at 50°C:	3.0...3.5°E/ 21...cSt 100...118 SSU 100°F
Viscosity index:	94
Neutralization figure:	0.02 mg KOH/g oil
Conradson test:	0.04%
Ash oxyd:	0.008%
Color per ASTM:	2.0
Bleaching earth consumption TONSIL L 80:	1.5%

60% of the spindle oil are non-emulsive as per ASTM.
40% of the spindle oil have 3...5 ml emulsion.

3. Spindle oil

Specific weight at 15.6°C/60°F:	0.873 kg/l
Flash point in open crucible C.O.C.:	180...190°C/ 356...374°F
Thickening point:	-15°C/5°F
Viscosity at 50°C:	1.6...2.2°E/ 7.5...14cSt 50...73 SSU 100°F
Viscosity index:	+92
Neutralization figure:	0.02 mg KOH/g oil
Conradson test:	0.04%
Ash oxyd:	0.006%
Color per ASTM:	2.0
Bleaching earth consumption TONSIL L 80:	1.5%

60% of the spindle oil are non-emulsive as per ASTM.
40% of the spindle oil have 5 to 6 ml emulsion.

4. Gas oil (fuel oil)

Specific weight at 15.6°C/60°F:	0.845 kg/l
Flash point in closed crucible as per PENSKY MARTENS:	55°C/131°F
Thickening point:	-24°C/-11°F
Viscosity at 20°C:	1.3°E/4 cSt/39.2 SSU 100°F
Ash oxyd:	0.05%
Neutralization figure:	0.03 mg KOH/g oil
Color per ASTM:	1.5
Boiling-course:	
Beginning of boiling:	120°C/248°F
Vaporization at 250°C/482°F	32%
Vaporization at 320°C/608°F	90%
Bleaching earth consumption:	1.0% TONSIL L 80
Calcium hydrate:	0.5%

5.4 ERDA Re-Refining Process

The ERDA process starts with the removal or "stripping" of water and volatile hydrocarbons. This is accomplished by distilling the used oil. The distillation process is vacuum distillation carried out at a temperature of about 300-345°F (174°C) and a pressure between 2-10 mm Hg.

The next step consists of combining the stripped oil with a solvent mixture. The ratio of the amount of solvent to be used to the amount of lubricating oil may vary from about 3-8 parts solvent to 1 part oil, the most preferable ratio being 3 parts solvent to 1 part oil. The oil dissolves in the solvent mixture and oxidation products, additives, metal components and other impurities in the oil precipitate out as sludge. The used oil is stripped to prevent the formation of azeotropes with the solvent mixture which may hinder solvent recovery. The preferred solvent composition is 1 part 1-propanol (isopropyl alcohol), 1 part methylethyl ketone to 2 parts 1-butanol (n-butyl alcohol), although the amount of each component present in the solution may vary up to about 10% by volume without unduly affecting the results attainable by the use of the solvent.

It is preferable that contact between the solvent mixture and the used oil take place at ambient temperature or below. Lower temperatures, down to about 50°F (10°C), will increase the effectiveness of the solvent by causing precipitation of more of the undesirable sludge and combustion products while temperatures higher than about 86-140°F (30-40°C) will reduce the effectiveness.

Generally, about 10% of the weight of the oil is precipitated by the solvent mixture. The solvent-oil mixture may be separated from the precipitate by any of the usual separation methods. For example, the mixture may be allowed to settle in a tank overnight followed by decantation of the solid-oil mixture. Alternatively, a centrifuge can be used to separate the sludge from the solvent-oil mixture immediately after mixing. The centrifuge might be used to provide either a continuous separation or a batch separation of sludge.

Recovery of the solvent mixture from the purified oil may be accomplished by any method known to those skilled in the art. For example, an evaporator/stripper with a suitable vacuum system and cold traps are suitable for solvent removal and recovery. In pilot-scale studies, effective solvent stripping was accomplished using a continuous-feed distillation column operated at 150 mm Hg abs. at 345°F (174°C). These conditions left about 0.1% of the solvent in the oil; a second pass through the column at 1 mm Hg abs. was used to improve solvent recovery. The recovered solvent can then be reused to purify additional dehydrated used oil, while the purified oil separated from the solvent is processed further.

Additional processing of the solvent-stripped purified oil will be necessary in order to prepare the oil for reuse as a lubricant. For example, the oil may be vacuum-distilled either fractionally or by taking a full boiling range oil distillate overhead. The distillate may be subjected to light hydrogenation or, alternatively, may be treated with a bleaching clay and dry steam at 250 to 450°F (121-232°C) for a short period of time to decolor and deodorize the oil. At this time the purified oil may be blended with a suitable group of new additives to prepare it for reuse as a lubricating oil.

The following example is given to illustrate the process described and is not to be taken as limiting the scope of the process.

5.5 Additional Re-refining Processes

S. R. Bethea and his associates at the Baytown Petroleum Research Laboratory, a division of the Exxon Research and Engineering Company in Baytown, Texas, have developed a process that consists essentially of vacuum distillation followed by hydrofining, a hydrogenation process for finishing the oil. Exxon has concluded, however, that it would be too difficult to try to license the process to the many small re-refiners and has placed the technology in the public domain. The U.S. EPA sponsored a study of the NORCO process. Both crankcase and other used oils were studied in the laboratory and in a 1000-barrel-per-day vacuum distillation process operated by National Oil Recovery Corporation in Bayonne, New Jersey, and based primarily on the Exxon technology.[24]

Plant operations demonstrated that vacuum distillation is a suitable process for producing fuels from a wide variety of used oils. Laboratory and engineering studies showed that the distillate side product produced from crankcase used oil could be catalytically hydrotreated to produce a lube with good odor, color, and stability characteristics. The distillation bottoms, containing high concentrations of lead and other metals, can be used as a fuel in secondary lead smelting.

Pretreatment and chemical reduction agents show promise in re-refining, but additional laboratory and evaluation work is required.[25]

A prototype plant using aqueous isopropyl alcohol as the extracting agent has been built in California by MZF Associates, Los Angeles. Capacity is expected to be 500,000 gallons per month. The plant's only by-product is expected to be a 30 percent-lead solid, amounting to 2 to 4 percent of the feed.

According to M. Z. Fainman, one of the developers, the method works by first diluting the used oil with naphtha recycled from a downstream process step. The combined hydrocarbon stream is mixed with a 50/50 extractant solution of isopropyl alcohol and water plus 1% sodium carbonate, and then the overall mixture goes through a centrifuge. Three fractions result: a sludge, an alcohol layer, and an oil layer (which is sent to vacuum distillation). The alcohol fraction is stripped to recover clean isopropyl alcohol and to drop out solids. These solids combine with the sludge, which is then dried and hauled away. The crude-oil product leaves the bottom of the vacuum distillation column and goes to further treating.

The main advantage of the extraction step is that it removes metals, clearing the way for successful distillation. Furthermore, metals removal enables downstream catalytic hydrogenation for upgrading the crude product.[26]

Institute Francais du Pétrole (IFP) has a more complicated process that it is trying to market in the United States. The process includes a short preliminary distillation, extraction with propane, treatment with acid, vacuum distillation, and finishing with clay. One plant using the IFP process is operating near Milan, Italy, and a second has been constructed in northern Europe.[24,27]

Edward T. Cutler and the late Louis E. Cutler of Pilot Research & Development Company, Merion Station, Pennsylvania, developed a process that consists of propane extraction, vacuum distillation, and hydrofining. The PVH process, as it is named, is thought by many to be highly innovative, but so far has been tested only on a laboratory scale. Pilot is currently seeking a company interested in constructing a test plant.

This PVH process follows these steps:

- Screen out large pieces of debris and thermally dehydrate the oil.
- Mix the dry oil with 4-6 times its volume of propane at 180-190°F and 600-700 psig. Settle this mix, drain off the bottoms and separate the clarified oil-propane mix.
- Strip the propane from the clarified oil-propane mix, condense it and store it for reuse. Collect the stripped oil.
- Vacuum fractionate the stripped oil at a pressure no greater than 10 torr and at a temperature no greater than 650°F, distilling all but 10-15% of the charge stock.
- Hydrogenate the condensed hot oil fractions over a catalyst consisting of one or more Group VI and/or VIII metal oxides or sulfides at 600-700°F, 600-700 psig.
- Strip the hydrogenated oil fractions of H_2, reduction products, and light ends.
- Cool and filter the oil.

The propane step removes 70-80% of the original oil impurities (high molecular weight additives, additive fragments and oil oxidation products, plus high-density particulates). Vacuum distillation removes 10-15% of the original used oil impurities (medium molecular weight additives, additive fragments, and oil oxidation products, plus low-molecular-weight salts, acids, and colloidal solids). Hydrogen removes the last 10-15% of the original impurities (low-molecular-weight additives, additive fragments, and oil oxidation products.[28]

Marvin L. Whisman and his associates at the Bartlesville Energy Research Center (BERC), an Energy Research and Development Administration (ERDA) laboratory in Bartlesville, Oklahoma, have developed a process where a mixture of organic solvents is used for the extraction, and either clay or hydrogenation can be used for finishing the oil. They have tested the process in leased pilot plants at three locations throughout the country.[29]

In comparing the BERC/ERDA solvent/clay-treated product with a commercial acid clay re-refined product, one finds an improvement in the BERC/ERDA oil with regard to residual additives and oxidation products.

The laboratory investigation found that oil with the lowest amount of oxidation resins and additives and the best color (ASTM 2.5) can be produced under the following conditions: (1) Dehydrate the used oil to remove 700°F end point distillates, (2) Mix the oil and BERC/ERDA solvent system at 55°F and continue gravity settling for seven days, (3) Decant and then solvent-strip the oil so that the distillation bottoms end point is 500°F, (4) Clay-treat the oil using 15% by weight Filtrol-20 for 6 hours at 550°F under a blanket of nitrogen, (5) Filter the oil clay slurry at 240°F.

An overall volumetric yield of about 75% on water-distillate-free oil can be expected at the levels of solvent and clay treating employed. Higher yields may be expected at higher solvent treating temperatures (greater than 55°F) and at lower (less than 15%) percentage clay treatment levels, provided that commercially acceptable base oils can be produced. Laboratory work indicates a possible reduction in the amount of clay used; however, data are not yet sufficient with regard to solvent treating temperature and sludge separation methods to permit specification of optimum conditions.

Some of the products that could be blended from this type of base stock are: (1) automotive oils which could range from no specification to one having SE/CD multigrade requirements, (2) recycling railroad engine oils, and (3) various industrial oils ranging from pure base stock to hydraulic oils.

Acknowledgements

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Thomas Chambers - Borg Warner Corporation
Roy Morris - Russell, Burdsall & Ward Corporation

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APPENDIX I

- Sample Selection Procedures for the Illinois Industrial Survey
- Cover letter for the Illinois Industrial Questionnaire
- Copy of the Illinois Industrial Questionnaire

Sample Selection Procedures for the Illinois Industrial Survey

The industries considered for the Illinois Industrial Questionnaire were confined to Standard Industrial Classification (SIC) categories 33 through 38. About 30 responses from each SIC category were sought to acquire a representative sample. Estimating a return rate of about 15 percent, 1500 questionnaires were sent out. It was hoped that the information obtained from the returned questionnaires could be expanded to state used oil totals per SIC.

The number of questionnaires mailed to each of the SIC categories 33 through 38 was based on the percent of used oil generated annually within each category (i.e., 17% of used oil is generated by category 33, so 17% of 1500 questionnaires or 255 were sent to industries in category 33. See Table I-1. The used oil produced by SIC categories 33 through 38 was taken to be 100%. All plants with an employee population of 250 or more were sent questionnaires because they represented the production of the majority of used oil. These large plants numbered 653 in the 6 SIC categories of interest leaving 847 plants to be chosen. (See Table I-1).

Table I-1

SIC Category	% of Used Oil Generated Annually	No. of Plants to be Surveyed According to the % of Used Oil Generated	No. of Plants with 250 or more employees	Remaining Plants to be Surveyed (< 250 employees)
33	17	255	90	165
34	37	555	145	410
35	18	270	183	87
36	16	240	145	95
37	7	105	51	54
38	5	75	39	36
	100	1500	653	847

The industrial plants having fewer than 250 employees were divided into two groups: one group consisting of industrial plants with an employee population between 1 and 49 and the other group made up of industrial plants with an employee population between 50 and 249. Of the remaining 847 questionnaires 75% were sent to plants having 50 to 249 employees and the remaining 25% were sent to plants having 1 to 49 employees. The questionnaires were mailed to industrial plants (of SIC categories 33 through 38) in all sections of the state of Illinois in an attempt to achieve representative geographical sampling. A breakdown of the 847 industrial plants to be surveyed in each group, along with the number surveyed in Chicago is listed in Table I-2.

Table I-2

Surveyed Plants

SIC Category	No. of Plants (1-49 Employees)	No. of Plants Chicago (1-49 Employees)	No. of Plants (50-249 Employees)	No. of Plants Chicago (50-249 Employees)
33	40	12	90	26
34	102	39	145	55
35	22	7	183	54
36	24	7	145	46
37	13	6	51	23
38	9	4	39	16
	210	65	637	225

The names and addresses of the industrial plants in SIC categories 33 through 38 were obtained from a mailing list provided by Manufacturer's News Inc. This mailing list consisted of coded, peel and stick mailing labels. The mailing labels contained the company name, address, SIC category and other information such as the area designation code, not necessary for our purpose.

To ensure that the companies surveyed were listed under the proper SIC category a space was provided on the questionnaire for the SIC number to be filled in. This questionnaire was unanimously endorsed by the Illinois Manufacturer Association's (IMA's) 85-member Environmental Quality Committee. A cover letter was sent with each questionnaire explaining its significance. Copies of the cover letter and questionnaire appear in this Appendix.

The returned questionnaires were handled by the IMA. Here each responding firm's name and address was separated from the rest of the questionnaire before the returned questionnaire was forwarded to ETA for analysis. The detached company name and the questionnaire were correspondingly numbered to enable ETA to contact firms regarding their responses through the IMA.

IMA
Illinois Manufacturers' Association

March 2, 1977

To help Illinois industry and the environment, we urge you to complete the enclosed "Industrial Used Oil Questionnaire," and return it to the Illinois Manufacturers' Association, 135 South LaSalle Street, Room 2040, Chicago, Illinois 60603 by March 17, 1977.

Used oil is being singled out by the Illinois Division of Energy as an important energy resource and as a re-refinable oil which can be used for industrial lubricating. The Division of Energy may seek legislative authority to regulate the use of lubricating oils by proposing legislation in the 1977 session of the Illinois General Assembly. At the same time, the Illinois Environmental Protection Agency, through its proposed hazardous waste hauling regulation (R76-10) plans to tightly control the disposal of used lubricating oils.

To guide the state of Illinois in addressing the used lubricating oil problem from these perspectives, a state research agency, the Illinois Institute for Environmental Quality (IIEQ) has undertaken a used oil study, a large portion of which will be done by Environmental Technology Assessment (ETA), a private consulting firm. Purpose of the study is to determine how much used oil is going to disposal sites, is dealer re-refined, and is being used as a fuel and to gather as many additional facts on this problem as possible. The IIEQ plans to make this study an integral part of the economic impact study on R76-10 which the IIEQ must complete by law.

The study's success or failure depends upon the receipt of enough responses to the questionnaire to make the sample meaningful. Because most of such oils are used by industry, ETA sought and has received I.M.A.'s cooperation in the survey. The I.M.A.'s 85-member Environmental Quality Committee, at a recent meeting, unanimously endorsed the enclosed questionnaire. We urge you to complete it in the interests of accurately determining the extent of the problem and whether and what kind of regulations are needed.

Neither your company's name nor your name will be revealed by the I.M.A. to anyone nor will they be identified with your responses in any manner. The answered questions and the respondent's name will be coded and separated by the I.M.A. When all summary information is passed to ETA for inclusion in the study, all I.M.A. records will be destroyed. Published copies of ETA's final report will be available through the National Technical Information Service. Please return the questionnaires to I.M.A. by March 17, 1977.

Sincerely,

Malcolm Chester

Malcolm Chester, Director
Energy and Environmental Programs

135 South LaSalle Street, Chicago, Illinois 60603 (312) 641-6771
Springfield Office: 524 South Second Street, Springfield, Illinois 62701 (217) 522-1240

INDUSTRIAL USED OIL QUESTIONNAIRE

SIC CODE:

1. Please Indicate the types and approximate amounts of industrial lubricants that you purchase in a year (preferably 1975).

	Type of Oil	Annual Amount (gals./yr.)
☐	Water soluable cutting oils	
☐	Straight cutting oils	
☐	Heat treating oils	
☐	Gear & transmission oils	
☐	Lube & hydraulic oils	
☐	Synthetic oils	
☐	Others (please describe):	
	Total	

2. If you purchase re-refined oils from a re-refiner, or if you have a recycling program with a re-refiner, please indicate the types and amounts involved in a year (preferably 1975).

☐ Purchase re-refined oils from re-refiner.

☐ Have recycling program with a re-refiner.

	Type of Oil	Annual Amount (gals./yr.)
☐	Water soluable cutting oils	
☐	Straight cutting oils	
☐	Heat treating oils	
☐	Gear & transmission oils	
☐	Lube & hydraulic oils	
☐	Synthetic oils	
☐	Others (please describe):	
	Total	

Please indicate the name and address of the re-refiner.

3. Are you presently recycling any of your used oils for reuse in-house?

☐ Yes ☐ No

If "yes," would you please give a brief description of the process involved.

Would you also indicate the types and approximate annual amounts that you save through your reuse program.

	Type of Oil	Annual Amount (gals./yr.)
☐	Water soluable cutting oils	
☐	Straight cutting oils	
☐	Heat treating oils	
☐	Gear & transmission oils	
☐	Lube & hydraulic oils	
☐	Synthetic oils	
☐	Others (please describe):	

4. What are the types and approximate amounts of used oils that you have to dispose of in a year (preferably 1975).

* Note: For purposes of this survey, a "used oil" will be any waste having an oil content greater than 30%.

Type of Oil	Annual Amount (gals./yr.)
☐ Water soluable cutting oils	
☐ Straight cutting oils	
☐ Heat treating oils	
☐ Gear & transmission oils	
☐ Lube & hydraulic oils	
☐ Synthetic oils	
☐ Others (please describe):	
Total	

5. Please indicate how your waste oils are being disposed of, and the amount involved with each method over a yearly period (preferably 1975).

A. Haul it away ourselves:

Method	Amount (gals./year)
☐ a. To incinerator	
☐ b. To landfill	
☐ c. For road oiling	
☐ d. For dust control	
☐ e. To processor	
☐ f. To another industry	
☐ g. To lagoon	
☐ h. To dump	
☐ i. Other (please specify):	
Total	

B. Picked up by outside collector.

(Please give hauler's name and annual amount.)

Company	(gals./year)

C. On-site disposal:

Method	Amount (gals./year)
☐ a. Burned as fuel	
☐ b. Tank storage	
☐ c. Into sewer	
☐ d. Treatment plant	
☐ e. Dust control	
☐ f. Road oiling	
☐ g. Other (please specify):	
Total	

6. Do you have holding (storage tank facilities for used oils?

☐ No

☐ Yes ____________ How often is (are) it (they) emptied? ____________

Capacity (gallons)

7. Do you segregate any of your used oil streams or do you combine all your waste oils?

☐ Combine all of them

☐ Segregate one or more waste oils

If you do segregate, would you please give a brief description.

8. DO YOU USE WASTE OILS FROM ANOTHER INDUSTRY?

☐ YES ☐ NO

DO YOU PARTICIPATE IN A WASTE OIL EXCHANGE PROGRAM?

☐ YES ☐ NO

IF YES, WOULD YOU PLEASE INDICATE WHAT TYPE AND ANNUAL AMOUNT?

TYPE	AMOUNT (GALLONS/YEAR)

9. WITH RESPECT TO YOUR CURRENT ARRANGEMENTS FOR STORING, HANDLING AND DISPOSING OF WASTE OILS, HOW WOULD YOU RATE YOUR PRESENT AND FUTURE WASTE OIL SITUATION. (CONSIDER CURRENT AND PENDING LEGISLATION.)

☐ NO CURRENT PROBLEMS OR FUTURE PROBLEMS.

☐ NO CURRENT PROBLEMS, BUT FORESEE FUTURE PROBLEMS.

☐ HAVE CURRENT PROBLEMS AND FORESEE FUTURE PROBLEMS.

PLEASE FEEL FREE TO USE THE FOLLOWING SPACE (PLUS ANY ADDITIONAL PAGES) TO ELABORATE ON YOUR PARTICULAR PROBLEMS AND ANY IMPROVEMENTS OR ADDITIONAL COMMENTS YOU MAY HAVE.

RESPONDENT'S NAME: ______________________

TITLE: ______________________

COMPANY NAME: ______________________

BUSINESS ADDRESS: ______________________

BUSINESS TELEPHONE: ______________________

Table I-3

The Number of Responses to the Illinois Industrial Survey According to Plant Size

Plant Population Category		Number of Survey Responses
1-25		7
26-50		13
51-100		30
101-150		13
151-250		31
251-500		31
501-750		16
751-1000		17
1001-1500		12
1501-2000		7
2001-3000		7
3001-4000		5
>4000		7
	TOTAL	196

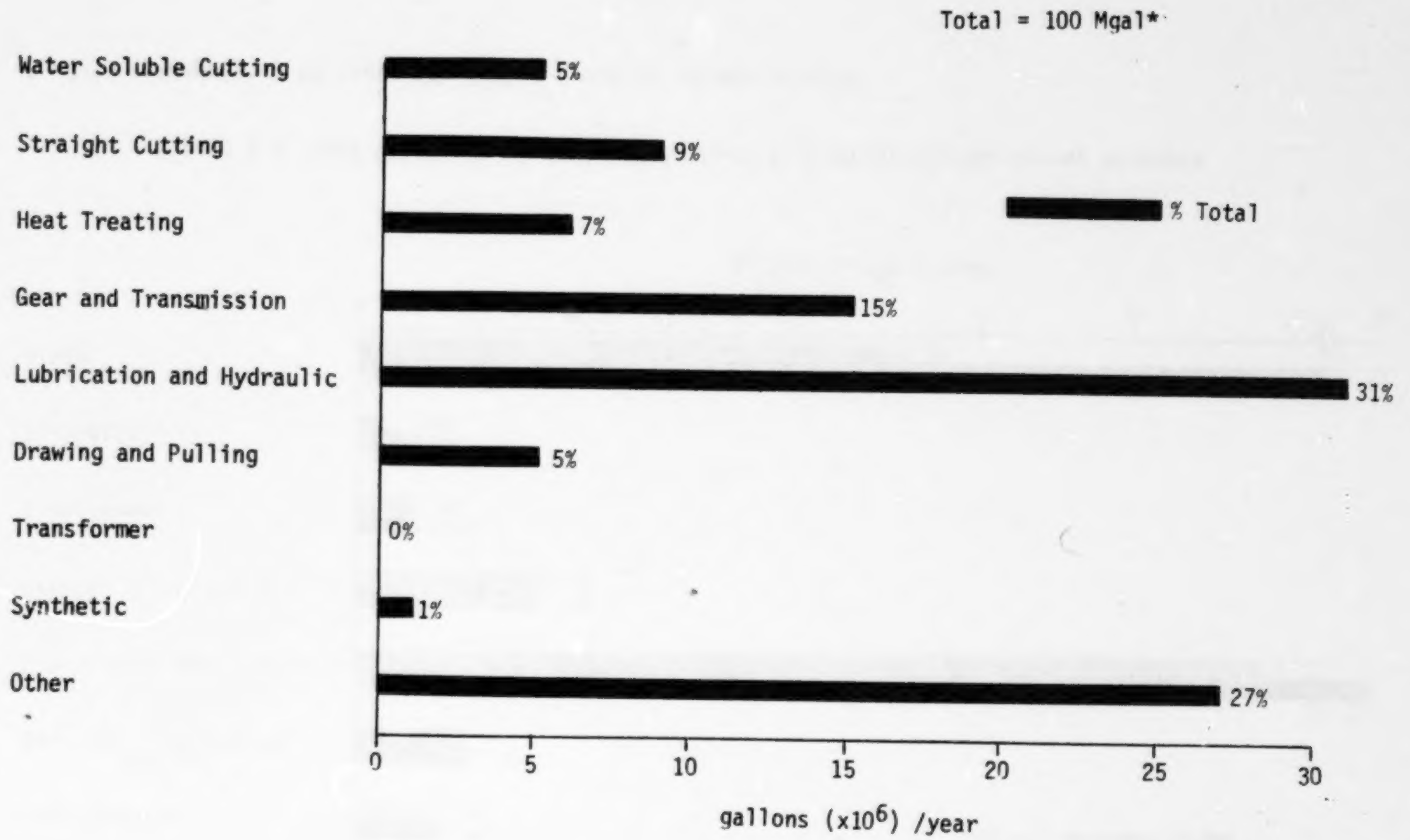

Figure I-1 Industrial Oil Purchases in Illinois

* 1973 data - see Table 2-1. The distribution is based on survey results.

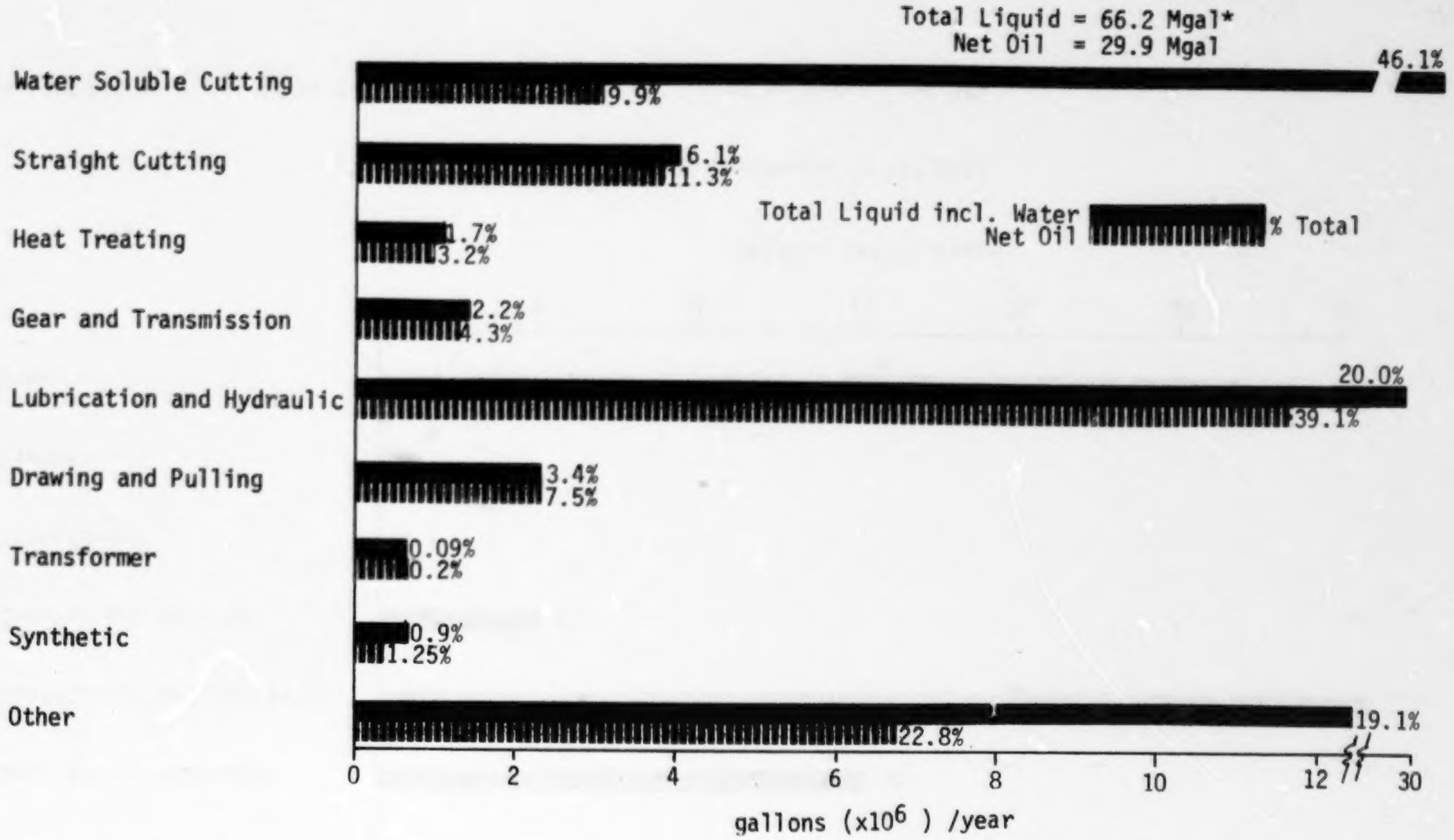

Figure I-2 Used Oil Disposal in Illinois According to Industrial Survey Response

* Data extrapolated to statewide totals based on survey results.

APPENDIX II

Oil Sample Analysis Results and Typical Properties of Fuel Oils and Some Lubricants

Table II-1

Circle Laboratory Results

SAMPLES	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SIC Category	33	35	33	33	34	37	34	35	34	34	37	---	34	35
A.P.I. Gravity	28.7	27.5	40.6	25.9	28.4	29.3	29.3	30.6	25.2	37.6	30.2	27.0	28.2	26.4
Ash Content (%)	0.34	0.03	0.04	0.13	0.22	0.50	0.23	0.28	0.37	0.08	0.21	0.25	0.05	0.36
Carbon Residue (%)	1.9	0.1	0.0	1.0	0.9	0.6	0.3	0.6	0.1	0.3	1.0	0.2	1.0	1.0
BS&W (%)	6.0/0.0	0.0/0.0	1.0/0.0	0.0/0.0	0.5/0.0	0.5/2.7	0.8/20.4	0.2/0.4	1.5/37.8	0.2/2.0	0.2/0.0	0.1/0.3	0.3/1.2	0.4/0.2
Pour Point (°F)	+59	+16	-22	-27	-9	-6	-20	-60	-40	+5	-10	-30	0	-60
Flash Point (°F)	475	525	315	470	---	280	330	235	195	280	355	340	325	220
Fire Point (°F)	520	600	345	500	---	285	420	245	210	310	375	350	360	220
Heat of Combustion (Btu/lb)	---	19,406	20,575	20,611	20,863	18,000	20,323	20,378	19,874	20,450	20,719	20,216	20,809	19,353
Viscosity (SUS @ 100°F)	261.6	1781.5	195.3	687.3	69.5	206.9	123.8	63.9	177.6	30.8	134.3	147.2	89.8	---
Viscosity (SUS @ 210°F)	---	145.8	42.4	84.4	22.4	23.3	28.1	24.0	---	10.8	27.2	31.7	28.0	---
Acid # (mgKOH/g)	---	1.4	1.3	1.1	0.7	---	1.4	2.0	4.5	0.6	1.5	2.5	---	---
Sulfur (%)	---	0.4	0.2	0.6	---	0.2	0.8	0.2	0.3	0.4	0.3	0.6	0.4	0.6
Silver (PPM)	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.6	0.1	0.5	---	0.1	0.3
Sodium (PPM)	9	0	0	0	0	97	0	25	40	10	7	---	0	33
Zinc (PPM)	4	1	39	10	14	39	530	30	23	7	200	---	3	100
Copper (PPM)	140	4	3	3	0	16	11	27	25	3	120	---	6	34
Aluminum (PPM)	12	1	1	3	1	6	3	9	65	30	4	---	3	22
Barium (PPM)	23	5	45	13	11	76	330	55	40	10	15	---	10	100
Nickel (PPM)	44	4	3	5	4	5	4	10	29	10	7	---	4	12
Chromium (PPM)	45	4	2	8	4	5	4	15	18	1	5	---	9	14
Calcium (PPM)	50	16	13	85	94	400	65	250	190	80	85	---	76	250
Iron (PPM)	1500	35	18	120	68	240	36	24	1000	110	900	---	27	170
Silicon (PPM)	9	1	11	5	4	29	6	680	650	20	19	---	4	37
Tin (PPM)	5	45	0	5	0	5	5	2	7	0	5	---	0	5
Lead (PPM)	19	90	7	150	4	230	100	31	170	17	24	---	27	700
Phosphorus (PPM)	340	10	90	50	19	2000	360	50	960	70	300	---	57	350
Boron (PPM)	2	1	1	2	1	2	1	4	5	2	2	---	2	8
Magnesium (PPM)	6	1	0	4	11	74	3	13	20	11	19	---	6	55
Vanadium (PPM)	1	2	1	2	1	2	4	11	5	0	1	---	1	15
Molybdenum (PPM)	2	1	0	1	2	1	1	1	2	0	0	---	0	1
Manganese (PPM)	21	1	0	12	3	95	1	11	250	17	9	---	64	17
Cadmium (PPM)	2	0	0	0	0	1	19	0	1	1	1	---	0	1
Titanium (PPM)	4	0	0	0	1	2	22	2	110	1	1	---	0	5

Note: Most of the sludge and water were removed from the samples by centrifuging and decanting the oil before analysis. BS&W test was done on the original samples.

Table II-2

ECHO Laboratory Results

OIL SAMPLE #	1	2	3	4	5	6	7	8	9	10	11
API Gravity	---	80.0	---	---	12.9	---	---	---	---	---	24.0
Ash (%)	0.04	0.17	---	3.10	---	0.20	0.26	0.56	2.12	0.16	---
Flash Point (°F)	150	150	80	225	---	150	150	150	150	150	---
Heat of Combustion (Btu/lb)	17,511	---	14,000	14,000	---	19,350	18,914	18,543	16,490	19,138	---
BS&W (%)	---	---	---	---	---	---	---	---	---	---	2.6
Sulfur (%)	0.00	0.00	0.90	0.40	---	0.21	0.3	0.01	0.02	0.02	0.85
Zinc (PPM)	27.9	---	174.0	23.0	89.6	187.0	216.0	38.1	49.6	51.0	---
Copper (PPM)	1.1	---	3.7	0.3	4.7	39.0	91.0	11.6	10.7	4.1	---
Chromium (PPM)	0.0	---	0.2	0.3	10.2	2.4	2.9	2.9	7.0	0.5	---
Lead (PPM)	3.6	---	49.0	2.3	84.2	23.2	13.0	17.0	126.0	8.0	---
Cadmium (PPM)	0.0	---	6.9	0.6	0.2	0.6	0.4	0.1	0.3	0.4	---

Table II-2

(continued)

OIL SAMPLE #	12	13	14	15	16	17	18	19	20	21	22	23
API Gravity	31.0	20.0	29.0	---	---	---	27.5	---	---	---	---	---
Ash (%)	0.45	---	---	1.60	0.10	3.90	17.00	0.29	---	---	0.13	14.00
Flash Point (^{o}F)	---	---	---	140	72	155	145	---	200	200	---	155
Heat of Combustion (Btu/lb)	---	---	---	10,000	19,500	15,000	12,000	---	14,826	12,443	---	8,300
BS&W (%)	0.7	2.4	3.8	---	---	---	---	---	---	---	---	---
Sulfur (%)	0.90	0.36	1.21	0.63	0.73	0.60	1.00	---	0.53	0.60	---	0.79
Zinc (PPM)	123.0	---	---	25.0	0.7	7.7	43.0	2.8	---	---	---	0.7
Copper (PPM)	6.7	---	---	54.0	1.4	10.0	65.0	---	---	---	---	0.6
Chromium (PPM)	---	---	---	2.2	0.1	0.1	22.0	---	---	---	---	0.0
Lead (PPM)	3.6	---	---	940.0	0.4	100.0	25.0	8.0	---	---	0.4	0.6
Cadmium (PPM)	14.0	---	---	0.1	0.0	0.0	0.0	7.0	---	---	4.0	0.1

Table II-3 Motor Oils Refining Company Laboratory Results

SAMPLES:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
A.P.I. Gravity	26.8	24.2	---	---	---	---	---	38.0	---	38.0	33.0	29.5	---	23.2	27.5	28.0	33.0
BS&W (%)	---	5	34	2	3	8	10	50	40	---	1	18	18	1	60	1	6
Flash Point (^{o}F)	---	---	---	---	---	---	---	290	---	280	200	---	---	300	---	350	260
Viscosity (SUS @ 100^{o}F)	838	873	656	2270	1000	730	452	100	210	42	69	234	76	129	77	266	65
Viscosity (SUS @ 210^{o}F)	91.6	73.8	72.9	132.0	90.0	81.0	61.0	39.5	57.0	---	37.0	49.0	38.0	40.7	37.3	50.2	36.8
Zinc (PPM)	25	5000	---	5	---	---	500	8	92	10	2	20	450	4	---	8	---
Copper (PPM)	1	460	---	11	---	---	32	20	1	20	1	60	380	10	---	20	---
Aluminum (PPM)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Barium (PPM)	55	23	---	25	---	---	10	75	0	40	70	15	70	0	---	10	---
Chromium (PPM)	1	21	---	4	---	---	5	25	18	10	3	3	18	3	---	5	---
Calcium (PPM)	21	220	---	0	---	---	750	200	6400	30	880	60	---	20	---	30	---
Iron (PPM)	12	1750	---	5	---	---	950	1000	5100	400	13	120	700	18	---	60	---
Silicon (PPM)	2	70	---	2	---	---	250	100	6	90	5	16	110	7	---	10	---
Lead (PPM)	7	300	---	37	---	---	25	22	28	20	2	55	2000	5	---	8	---
Phosphorous (PPM)	0	2500	---	10	---	---	425	800	600	700	0	40	400	0	---	10	---
Boron (PPM)	0	2	---	5	---	---	5	10	1	3	0	2	---	2	---	1	---
Manganese (PPM)	0	25	---	---	---	---	---	---	---	---	---	---	---	4	---	3	---
Cadmium (PPM)	3	3	---	0	---	---	0	3	5	2	0	5	3	0	---	1	---
SIC Category	28	28	33	33	33	33	33	33	33	33	33	33	34	34	34	34	35

Table II-3 (continued)

SAMPLES:	18	19	20	21	22	23	24	25	26	27	28	29
A.P.I. Gravity	25.0	30.0	30.5	28.9	25.5	29.5	27.6	32.5	28.5	29.0	28.5	29.0
BS&W (%)	1	3	76	---	10	6	8	90	26	74	9	5
Flash Point (^oF)	210	300	---	420	480	440	440	140	440	420	445	410
Viscosity (SUS @ 100^{o}F)	87	196	185	293	1200	299	584	43	468	393	348	229
Viscosity (SUS @ 210^{o}F)	37.6	46.1	45.9	53.4	90.0	52.6	67.5	32.0	63.2	66.5	55.1	52.5
Zinc (PPM)	1	---	250	---	1	500	---	---	---	---	420	270
Copper (PPM)	0	---	---	---	---	---	---	---	---	---	---	---
Aluminum (PPM)	---	---	2000	---	7	7	---	---	---	---	36	4
Barium (PPM)	0	---	190	---	10	0	---	---	---	---	10	550
Chromium (PPM)	1	---	9	---	4	7	---	---	---	---	3	5
Calcium (PPM)	0	---	85	---	50	10	---	---	---	---	0	1500
Iron (PPM)	12	---	375	---	33	55	---	---	---	---	20	13
Silicon (PPM)	1	---	2500	---	8	10	---	---	---	---	4	12
Lead (PPM)	1	---	78	---	17	10	---	---	---	---	780	30
Phosphorous (PPM)	0	---	700	---	10	450	---	---	---	---	300	100
Boron (PPM)	0	---	69	---	1	0	---	---	---	---	1	0
Manganese (PPM)	0	---	---	---	1	0	---	---	---	---	0	0
Cadmium (PPM)	0	---	---	---	0	0	---	---	---	---	0	0
SIC Category	35	35	37	37	37	37	37	37	37	37	37	37

Table II-4
Comparison of Used Oil Characteristics When Grouped by SIC Numbers

Sample	SIC #	API Gravity	Ash Content (%)	Pour Point (°F)	Flash Point (°F)	Fire Point (°F)	BS&W (%)	Carbon Residue (%)	Heat of Combustion (Btu/lb)	Viscosity (SUS) (100°F)	Viscosity (SUS) (210°F)	Acid # (mg KOH/g)
CIRCLE												
1	(3312)	28.7	0.34	+59	475	520	6.0	1.9	---	261.6	---	---
3	(3312)	40.6	0.04	-22	315	345	1.0	0.0	20,575	195.3	42.4	1.3
4	(3312)	25.9	0.13	-27	470	500	0.0	1.0	20,611	687.3	84.4	1.1
ECHO												
14	(339)	29.0	---	---	---	---	3.8	---	---	---	---	---
MOTOR OILS												
3	(33)	---	---	---	---	---	34.0	---	---	656.0	72.9	---
4	(33)	---	---	---	---	---	2.0	---	---	2270.0	132.0	---
5	(33)	---	---	---	---	---	3.0	---	---	1000.0	90.0	---
6	(33)	---	---	---	---	---	8.0	---	---	730.0	81.0	---
7	(33)	---	---	---	---	---	10.0	---	---	452.0	61.0	---
8	(33)	38.0	---	---	290	---	50.0	---	---	100.0	39.5	---
9	(33)	---	---	---	---	---	40.0	---	---	210.0	57.0	---
10	(33)	38.0	---	---	280	---	0.0	---	---	42.0	---	---
11	(33)	33.0	---	---	200	---	1.0	---	---	69.0	37.0	---
12	(33)	29.5	---	---	---	---	18.0	---	---	234.0	49.0	---
CIRCLE												
5	(3451)	28.4	0.22	-9	---	---	0.5	0.9	20,863	69.5	22.4	0.7
7	(3452)	29.3	0.23	-20	330	420	21.2	0.3	20,323	123.8	28.1	1.4
9	(3462)	25.2	0.37	-40	195	210	39.2	0.1	19,874	177.6	---	4.5
10	(3452)	37.6	0.08	+5	280	310	2.2	0.3	20,450	30.8	10.8	0.6
13	(3452)	28.2	0.05	0	325	360	1.5	1.0	20,809	89.8	28.0	---
ECHO												
9	(34)	---	2.12	---	150	---	---	---	16,490	---	---	---
4	(34)	---	3.10	---	225	---	---	---	14,000	---	---	---
10	(345)	---	0.16	---	150	---	---	---	19,138	---	---	---
12	(345)	31.0	0.45	---	---	---	0.7	---	---	---	---	---
13	(34)	20.0	---	---	---	---	2.4	---	---	---	---	---
22	(34)	---	0.13	---	---	---	---	---	---	---	---	---
MOTOR OILS												
13	(34)	---	---	---	---	---	18.0	---	---	76.0	38.0	---
14	(34)	23.2	---	---	300	---	1.0	---	---	129.0	40.7	---
15	(34)	27.5	---	---	---	---	60.0	---	---	77.0	37.3	---
16	(34)	28.0	---	---	350	---	1.0	---	---	266.0	50.2	---
CIRCLE												
2	(3519)	27.5	0.03	+16	525	600	0.0	0.1	19,406	1,781.5	145.9	1.4
8	(3522)	30.6	0.28	-60	235	245	0.6	0.6	20,378	63.9	24.0	2.0
14	(3522)	26.4	0.36	-60	220	220	0.6	1.0	19,353	---	---	---
ECHO												
20	(352)	---	---	---	200	---	---	---	14,826	---	---	---
21	(352)	---	---	---	200	---	---	---	12,443	---	---	---
23	(356)	---	14.00	---	155	---	---	---	8,300	---	---	---
1	(356)	---	0.04	---	150	---	---	---	17,511	---	---	---
5	(356)	12.9	---	---	---	---	---	---	---	---	---	---
8	(352)	---	0.56	---	150	---	---	---	18,543	---	---	---
MOTOR OILS												
17	(35)	33.0	---	---	260	---	6.0	---	---	65.0	36.8	---
18	(35)	25.0	---	---	210	---	1.0	---	---	87.0	37.6	---
19	(35)	30.0	---	---	300	---	3.0	---	---	196.0	46.1	---
CIRCLE												
6	(3714)	29.3	0.50	-6	280	285	3.2	0.6	18,000	206.9	23.3	---
11	(3741)	30.2	0.21	-10	355	375	0.2	1.0	20,719	134.3	27.2	1.5
ECHO												
11	(374)	24.0	---	---	---	---	2.6	---	---	---	---	---
19	(374)	---	0.29	---	---	---	---	---	---	---	---	---
MOTOR OILS												
20	(37)	30.5	---	---	---	---	76.0	---	---	185.0	45.9	---
21	(37)	28.9	---	---	420	---	---	---	---	293 .0	53.4	---
22	(37)	25.5	---	---	480	---	10.0	---	---	1200 .0	90.0	---
23	(37)	29.5	---	---	440	---	6.0	---	---	299 .0	52.6	---
24	(37)	27.6	---	---	440	---	8.0	---	---	584 .0	67.5	---
25	(37)	32.5	---	---	140	---	90.0	---	---	43 .0	32.0	---
26	(37)	28.5	---	---	440	---	26.0	---	---	468 .0	63.2	---
27	(37)	29.0	---	---	420	---	74.0	---	---	393 .0	66.5	---
28	(37)	28.5	---	---	445	---	9.0	---	---	348 .0	55.1	---
29	(37)	29.0	---	---	410	---	5.0	---	---	229 .0	52.5	---

Table II-5

Oil Property Sample Analysis

UI/Motor Oils/ECHO

	Mean	Max.	Min.	Range	Standard* Deviation
API Gravity	28.9	40.6	12.9	27.7	4.85
Ash Content (%)	1.08	14.00	0.03	13.97	2.91
Carbon Residue (%)	0.68	1.90	0.00	1.90	0.51
BS&W (%)	15.1	90.0	0.0	90.0	22.8
Pour Point (^{O}F)	-13.3	59.0	-60.	119.0	30.5
Flash Point (^{O}F)	302	525	140	385	113
Fire Point (^{O}F)	365	600	210	390	119
Viscosity (100^{O}F)	372	2270	30.8	2240	469
Viscosity (210^{O}F)	53.4	145.8	10.8	135	28.3
Acid # (mg koh/g)	1.6	2.0	0.6	1.4	1.1
Heat of Combustion (Btu/lb)	18131	20863	8300	12563	3287

---

*68% of all observations are within one standard deviation of the mean.
95% of all observations are within two standard deviations of the mean.
99% of all observations are within three standard deviations of the mean.

Table II-6 Grades and Types of Fuel Oils

Grade of Fuel Oil	Flash Point deg F (deg C)	Pour Point deg F (deg C)	Water and Sediment percent by vol	Carbon Residue on 10 percent Bottoms, percent	Ash percent by weight	Distillation Temperatures deg F (deg C)			Saybolt Viscosity, sec				Kinematic Viscosity centistokes				Gravity deg API	Copper Strip Corrosion
						10 per cent point	90 percent point		Universal at 100°F (38°C)		Furol at 122°F (50°C)		At 100°F (38°C)		At 122°F (50°C)			
	Min	Max	Max	Max	Max	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
No. 1 A distillate oil intended for vaporizing pot-type burners and other burners requiring this grade of fuel	100 or legal (38)	0	trace	0.15	--	420 (215)	--	550 (288)	--	--	--	--	1.4	2.2	--	--	35	No.3
No. 2 A distillate oil for general purpose domestic heating for use in burners not requiring No. 1 fuel oil	100 or legal (38)	20°[c] (-7°)	0.10	0.35	--	d	540[e] (282)	640 (338)	(32.6)[f]	(37.93)	--	--	2.0[e]	3.6	--	--	30	--
No. 4 Preheating not usually required for handling or burning	130 or legal (55)	20 (-7)	0.50	--	0.10	--	--	--	45	125	--	--	(5.8)	(26.4)	--	--	--	--
No. 5 Preheating may be required depending on climate and equipment	130 or legal (55)	--	1.00	--	0.10	--	--	--	150	300	--	--	(32)	(65)	--	--	--	--
No. 5 (heavy) Preheating may be required for burning and, in cold climates, may be required for handling	130 or legal (55)	--	1.00	--	0.10	--	--	--	350	750	(23)	(40)	(75)	(162)	(42)	(81)	--	--
No. 6 Preheating required for burning and handling	150 (65)	--	2.00[g]	--	--	--	--	--	(900)	(9000)	45	300	--	--	(92)	(638)	--	--

[a] Recognizing the necessity for low-sulfur fuel oils used in connection with heat-treatment, nonferrous metal, glass, and ceramic furnaces and other special uses, a sulfur requirement may be specified in accordance with the following table:

Grade of Fuel Oil	Sulfur, max, percent
No. 1	0.5
No. 2	0.7
No. 4	no limit
No. 5	no limit
No. 6	no limit

Other sulfur limits may be specified only by mutual agreement between the purchaser and the seller.

[b] It is the intent of these classifications that failure to meet any requirement of a given grade does not automatically place an oil in the next lower grade unless in fact it meets all requirements of the lower grade.

[c] Lower or higher pour points may be specified whenever required by conditions of storage or use.

[d] The 10 percent distillation temperature point may be specified at 440°F (226°C) maximum for use in other than atomizing burners.

[e] When pour point less than 0°F is specified, the minimum viscosity shall be 1.8cs (32.0 sec, Saybolt Universal) and the minimum 90 percent point shall be waived.

[f] Viscosity values in parentheses are for information only and not necessarily limiting.

[g] The amount of water by distillation plus the sediment by extraction shall not exceed 2.00 percent. The amount of sediment by extraction shall not exceed 0.50 percent. A deduction in quantity shall be made for all water and sediment in excess of 1.0 percent.

Source: ASTM Designation: D396-67, Book of ASTM Standards.

Table II-7

Types of Lubricating Oils (Petroleum)
Sample Inspections of Types and Classifications

Application	Automotive Crankcase	Automotive Crankcase	Automotive Crankcase	Automotive Transmission	Automotive Hypoid Gear	Aircraft Engine
Classification	Regular	Premium	Heavy Duty			
Inspection						
Gravity (°API)	22.1	28.0	27.1	19.0	18.8	26.5
Viscosity (S.U.V.)						
at 100°F	609	538	557	---	---	1616
at 130°F	240	240	248	---	---	645
at 210°F	59.2	65.9	66.8	72.5	86.4	118.5
Viscosity index	42	99	98	---	---	99
Flash point (°F)	390	440	435	370	415	535
Fire point (°F)	445	505	500	---	---	610
Pour point (°F)	-10	5	0	10	-5	5
Color (ASTM)	3.5	4.5	5.8	---	---	5.0
Sulfur (%)	---	0.3	0.4	---	---	0.3
Carbon residue (%)	0.1	0.3	0.9	---	---	0.5
Acid number	0.04	0.03	0.03	---	---	0.03
Saponification No.	---	---	---	---	---	---
Ash (%)	Nil	---	0.5	0.4	---	Nil
Contains additives	No	Yes Antiox.	Yes Detergent	Yes Thickener	Yes E.P.	No

Application	Steam Turbine	Textile Spindles	Cylinder (Steam)	Marine Engine	Cutting Sulfur	General Lubricating
Classification	Light				Saponifiable	
Inspection						
Gravity (°API)	31.8	33.4	25.8	20.3	29.9	58-3550
Viscosity (S.U.V.)						
at 100°F	150	73	2130	715	89.2	---
at 130°F	85	53	820	285	60.4	---
at 210°F	43.6	36	140	71	39.1	---
Viscosity index	108	---	---	---	---	< 0->100
Flash point (°F)	405	340	555	365	345	0- 105
Fire point (°F)	460	380	630	405	380	---
Pour point (°F)	0	-5	15	-15	15	---
Color (ASTM)	1	Light	6.50	5.50	Dark	---
Sulfur (%)	---	---	---	---	---	---
Carbon residue (%)	0.0	Nil	0.7	0.5	0.3	---
Acid number	0.03	0.03	0.06	0.90	0.60	---
Saponification No.	---	---	---	---	---	---
Ash (%)	Nil	Nil	Nil	Nil	Nil	Nil
Contains additives	Yes Antiox.	Yes Antiox.	Yes Emulsifier + Oiliness	Yes Emulsifier + Oiliness	Yes E.P. + Oiliness	Usually not; may contain antiox.

Source: Wiley, John and Sons, Handbook of Engineering Fundamentals, Eshback, 1961.

APPENDIX III

Case Study of Five Industrial Plant Oil Paths

The Oil Path at Five Metal-Working Plants

To obtain a better look at how a few individual industrial plants handle their used oil, information was collected at five metal-working plants. At four of the plants, used oil samples were taken to look at the quality of these oils at selected points in the plant.

1) Borg-Warner Spring Division Plant, Bellwood, Illinois

Machinery and automotive parts are manufactured in this plant. Quench, cutting transmission, hydraulic and other lube oils that have been used are dumped in sectional dump stations, and from there are pumped to the equalization tank at the oil recycling-water treatment facility. All of these mixed oils are then cleansed for supplemental fuel use.

The Oil Cleansing Process

The equalization tank at the treatment plant serves as a stabilizer to keep the flow rate of the oils and water pumped into the oil-water separators constant. From the equalization tank, the oil and water are pumped to an AIP gravity separator in which the free oil floats on top, and from there is pumped to the first storage tank. The water-emission phase which stays at the bottom is pumped to the mix tank where it is air mixed with emulsion breaking polymers and sulfuric acid. The mixture is usually maintained at a pH of 5.5-6 which is the optimum pH for the emulsified oil to precipitate. The floc formed is taken to a large gravity settling tank, where it is allowed to separate from the aqueous phase, and overflow to another tank from which it is pumped to the first storage tank. Again this storage tank is used as a gravity settling tank, and the oil from the top is pumped to the second storage tank.

From this tank the oil is pumped through a heater where the temperature of the oil is raised to 100°F. Next, the oil flows through a filter and is accumulated in a storage heating tank where it is kept for about 24 hours, and is then heated to 150°F, to assist in the separation of any water or sludge that may have accompanied it to this stage. From here the oil is pumped to the fuel storage tank where it is mixed with the fuel oil at a ratio of 1:1.

Oil Sample Test Results

Bench tests of oil samples taken from the plant indicate that contamination levels are reduced considerably by the process described above. These test results are shown in Table III-1 (1A-4A). Three mixed used oil samples were taken from three intermediate collection points and analyzed, then a sample of the oil was taken after it had gone through the cleansing process.

2) General Electric Company, DeKalb, Illinois

This General Electric plant manufactures electric motors for appliances. A variety of oils are used in the plant including general lubricating, hydraulic, cutting oils, and water soluble oils.

General Electric has a simple setting and filtration program for oil reuse. The reclaimed oil is circulated back into the original system. When the oils are too contaminated for this simple process, they are all collected in a tank and pumped out by an outside waste collector. No oil is reutilized as a fuel supplement.

From the G.E. oil samples listed in Table III-1 (1B-8B), it can be seen that the straight lubricating oil samples would make good candidates

Table III-1
Laboratory Used Oil Analysis Results for Samples Taken From Selected Industrial Plants

Sample #	1A	2A	3A	4A	1B	2B	3B	4B	5B	6B	7B	8B	1C	2C	3C	1D	2D	3D	4D
A.P.I. Gravity	29.3	--	--	20.7	25.8	--	33.4	28.0	28.4	--	2.1	31.0	25.7	28.8	--	26.8	30.4	29.7	22.0
Ash Content (%)	--	--	--	--	--	0.05	0.02	0.16	0.20	0.06	--	0.02	0.35	0.20	0.15	0.64	0.22	0.03	0.16
Carbon Residue (%)	--	--	--	--	--	0.1	0.2	0.6	0.5	0.4	--	0.0	1.6	0.4	0.7	1.1	0.2	0.7	2.2
BS&W (%)	0.0/0.0	0.6/0.0	0.30/30.0	0.6/0.0	0.0/0.0	1.3/0.0	1.3/0.0	--	1.3/0.0	1.3/0.0	--	1.3/0.0	7.5/5.0	1.3/0.0	27.4/0.0	1.3/0.0	1.3/0.0	1.3/0.0	3.8/0.0
Pour Point (°F)	-50	0	+10	-20	+20	+5	-60	+14	+14	-55	--	+10	+5	+15	-30	-25	-20	-10	-25
Flash Point (°F)	400	--	--	370	--	270	200	395	415	170	--	440	--	475	400	410	415	380	380
Fire Point (°F)	440	--	--	435	--	290	212	455	475	180	--	480	--	535	415	445	440	420	405
Heat of Combustion (Btu/Lb)	--	--	--	--	19,500	20,000	20,000	19,000	19,000	18,500	--	18,600	21,000	19,700	--	18,000	18,800	6,700	17,800
Viscosity (SUS @100°F)	141.3	310.8	--	324.7	1546.1	27.4	77.7	243.8	545.5	53.5	229.0	230.8	--	738.2	275.6	260.6	244.9	121.4	196.3
Viscosity (SUS @210°F)	47.4	98.7	--	75.4	126.4	10.3	19.6	72.1	90.3	44.1	83.9	49.5	--	93.5	54.0	67.4	49.6	29.8	31.8
Acid # (mg KOH/g)	--	--	--	--	0.4	0.3	0.3	1.2	1.5	1.0	--	0.2	--	0.4	--	--	2.0	0.5	--
Sulfur (%)	0.3	0.5	0.1	0.2	0.5	0.3	0.4	0.4	0.5	0.5	0.1	0.4	0.1	0.3	--	0.4	0.4	1.4	0.3
Silver (PPM)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	--	0.0	0.0	0.0	0.0
Sodium (PPM)	3	20	370	25	12	1	1	1	1	19	400	4	1	1	--	85	1	100	180
Zinc (PPM)	5	330	6	12	200	190	47	580	350	36	160	56	1100	160	--	760	600	29	12
Copper (PPM)	7	24	6	12	3	12	10	3	10	9	15	16	1160	140	--	140	7	2	150
Aluminum (PPM)	2	17	12	8	3	3	5	3	3	3	39	3	36	3	--	24	2	3	33
Barium (PPM)	5	36	36	34	220	7	13	7	30	45	--	10	35	240	--	120	5	17	120
Nickel (PPM)	0	0	21	0	0	0	0	0	0	0	4	0	27	0	--	0	0	0	5
Chromium (PPM)	4	14	31	10	5	1	7	5	7	16	7	3	8	6	--	16	3	2	28
Calcium (PPM)	0	220	100	200	38	82	15	0	0	0	0	0	180	53	--	470	0	0	1900
Iron (PPM)	24	170	190	100	6	18	21	2	11	31	18	1	200	20	--	85	2	42	520
Silicon (PPM)	3	16	44	32	2	2	33	2	4	63	22	2	62	6	--	22	2	2	90
Tin (PPM)	2	8	10	6	7	8	3	3	6	6	140	3	40	4	--	25	1	12	21
Lead (PPM)	1	260	7	15	4	8	3	4	3	11	50	4	23	8	--	1400	4	25	15
Phosphorus (PPM)	110	390	13	58	58	15	13	210	120	70	270	62	1080	100	--	400	200	22	150
Boron (PPM)	0	0	0	0	0	0	0	0	12	0	2	0	0	0	--	80	0	0	120
Magnesium (PPM)	2	25	90	26	1	1	2	3	4	3	11	0	45	1	--	1000	0	3	42
Vanadium (PPM)	5	10	5	8	6	0	9	6	7	19	7	3	4	6	--	8	3	2	8
Molybdenum (PPM)	0	1	1	1	1	1	1	1	1	2	16	0	19	1	--	2	1	0	7
Manganese (PPM)	3	6	124	6	3	6	4	3	4	7	20	3	16	3	--	9	3	69	17
Cadmium (PPM)	3	3	4	4	4	5	3	4	3	1	21	8	7	4	--	8	4	4	3
Titanium (PPM)	0	7	1	0	0	0	1	0	0	1	21	0	1	0	--	0	0	20	0

Table III-1 (continued)

Sample Description

Sample	1A	2A	3A	4A	1B	2B	3B	4B	5B
Description	*Recycled Waste Oil	*Mixed Waste Oil	*Mixed Waste Oil	*Mixed Waste Oil	**Used Draw. Oil for Punch Press	Used Cutting Oil	Mixed Waste Oil	Used Hydraulic Oil	Filtered Lube for Punch Press

Sample	6B	7B	8B	1C	2C	3C	1D	2D	3D
Description	Mixed Waste Oil	Water Soluble Oil	Used Hydraulic General Purpose	**Mixed Used Oil Separated Oil Skimmer	Light Gear Oil Used in Casting	*Fabricating Used Oil Used for Stripping & Stamping	Used Transmission oil From Fork Lift	Used Hydraulic Oil	Machine Oil, Not Dumped Just Topped

Sample	4D
	Machine Cutting Oil - One Month Old

A = Borg-Warner

B = General Electric

C = Olin Brass

D = John Deere

* Insufficient sample to complete all tests.

** Volatile components prevented performing tests that required heating.

for further recycling either back into the lubricating or fuel oil streams.* Significant treatment of the samples analyzed would be required in most cases to bring the oils back to original specifications, however this would not be the case for supplemental fuel use. The heavy metal concentrations are relatively low. Viscosities measured at 100°F vary considerably. One of the problems with burning the oils is that the flash point is considerably higher than the recommended value which ranges from 100-150°F. With these samples, however, all deviations from specifications could easily be corrected with virgin fuel blending.

The company is presently experimenting with synthetic oils which have thus far proven that they are worth the additional initial expense in terms of susceptibility to bacterial contamination and equipment wear.

3) Olin Brass Division of the Olin Corporation, East Alton, Illinois

Olin Brass produces copper and copper-alloy strip. Some of this strip is used at East Alton for the production of ammunition cups, fabricated parts, coin blanks, and solar collection panels.

The principal types and approximate quantities of oils and solvents that were purchased in 1976 at the plant are listed below.

Type of Oil	Annual Amount (Gals/Yr)
Water Soluble Cutting Oils	71,060
Straight Cutting Oils	30,855
Heat Treating Oils	55

---

*A few samples taken had to be discarded because of high contamination levels. In most cases this involved high water or volatile contents.

Type of Oil (Contd.)	Annual Amount (Gals/Yr)
Gear and Transmission Oils	7,865
Lube and Hydraulic Oils	89,406
Synthetic Oils	385
Degreasing Solvents	17,258
Rolling Oils	298,610
Total	515,494

Records show that there were 397,000 gallons of oily waste disposed of in 1976 and of this amount 68% was water. When the water is subtracted out, disposal records show that 127,000 gallons of oil are being hauled away by waste collectors. In the two wastewater treatment facilities about 118,200 gallons of oil and grease per year are collected in the sludge and about 1,940 gallons per year are discharged with the treated wastewater. The discharge is 9% of the amount permitted by Illinois Water Pollution Control Regulations. Hauling, sludge, and wastewater together account for 247,140 gallons, or 48% of the total oils purchased. About 2/3 of the Rolling Oils are burned in annealing operations which follow rolling, accounting for an additional 200,000 gallons per year, or totally 87% of the purchased oil and grease. Some will also leave the plant with the product, and some as part of solid waste in the form of sweepings or metal scrap.

Of the approximately 200 industries responding in the industrial survey, plants listed on average that they disposed of 1/4 of their puchased oil.

There is presently no used oil recycling program at this Olin plant.

Three of the six oil samples collected from this plant were analyzed in the laboratory and the results are presented in Table III-1 (1C-3C). These samples were from the following sources:

1C - Zone 17 Waste-Water Treatment Facility Oil Skimmer

2C - Zone 17 Waste Oil Storage

3C - Zone 1 Waste Cupping Compound Storage

Not analyzed were samples from the Rolling Mill of waste prosol/water mixture, waste mineral rolling oil, and waste hydraulic oil.

The waste hauling service that handles most of Olin's used oils charges for the removal of the oils and then deposits all of the oils in a retention pond at another industrial plant site. The waste hauler said that industrial oils, kerosene, crankcase oil and any other substance with an oily base are dumped into this pond and are used as boiler fuel.

4) Deere & Company, Moline, Illinois

John Deere manufactures farming equipment in the East Moline Harvester Works and the Plow-Planter Works plants. The principal types and quantities of oil purchased in 1976 for the Harvester plant were:

Type of Oil		Annual Amount Purchases (Gals/Yr)
Water Soluble Cutting Oils		39,160
Straight Cutting Oils		1,045
Heat Treating Oils		4,235
Gear & Transmission Oils		10,075
Lube & Hydraulic Oils		34,265
	Total	88,780

The quantity of oily waste disposed of in 1976 according to liquid waste hauling records was 37,000 gallons, of which 14,260 was oil after the water is subtracted out. Therefore, the Harvester plant has waste disposal records which account for 16% of the purchased oil. It is estimated by plant personnel that a large fraction of the remaining 84% leaves the plant with scrap metal chips and turnings.

The two John Deere plants visited do not presently have an active oil reuse program. The Harvester plant does reuse approximately 4,500 gallons per year for road oiling at the plant site. The John Deere Technical Center has been working on methods to extend lubricant life and has developed some proprietary equipment for this program.

The Dubuque John Deere plant has been experimenting with several methods of extending oil life and reusing spent lubricants. Much of the used oil presently produced is being burned in an incinerator. The incinerator provides steam for factory space heating and process steam.

Four oil samples from John Deere were analyzed in the laboratory. Samples 2D and 4D show a high carbon residue which means that these two oils would need cleansing before being reused. All four samples could be reused as a lubricant requiring less rigid specifications or a supplemental fuel with relatively minor prior treatment. Of course, re-refining with additives would be required for the oils to meet original specifications.

5) Russell, Burdsall & Ward Corporation, Rock Falls, Illinois

This plant manufactures screws, bolts, and nuts. Two reclamation processes have been used for many years, one for straight lubricating oils and the other for cutting oils. These two processes are described in detail below.

A. Reclamation System for Lubricating Oil

A central lube oil reclamation system has been in service for ten years (see Figure III-1) to clarify and return a general purpose machine oil of 400 sus at 100°F viscosity. It serves about 150 machines consisting of boltmakers, headers, cold nut formers, rod headers, trimmers, and threaders.

Oil Collection

Oil is collected from machine sumps and base pans with a vacuum oil cart. The cart is drained into a dirty oil tank in the basement recovery room. Some machines in the immediate vicinity drain by gravity directly into this tank.

Oil Settling

Oil is pumped from the dirty oil collection tank into a 500-gallon cone bottom settling tank. Oil is steam heated to 170°F and held overnight for settling. Bottoms are manually drained to a collection drum. Normally one 500-gallon batch of oil is processed daily.

Oil Filter

Clarified oil from the cone tank is pumped through a 3 micron cartridge filter and then into a clean oil holding tank.

Oil Distribution

Processed lube oil is returned to the operating departments primarily through an overhead distribution system. This process consists of two 100-gallon storage tanks with gravity drops to the machines. The feed

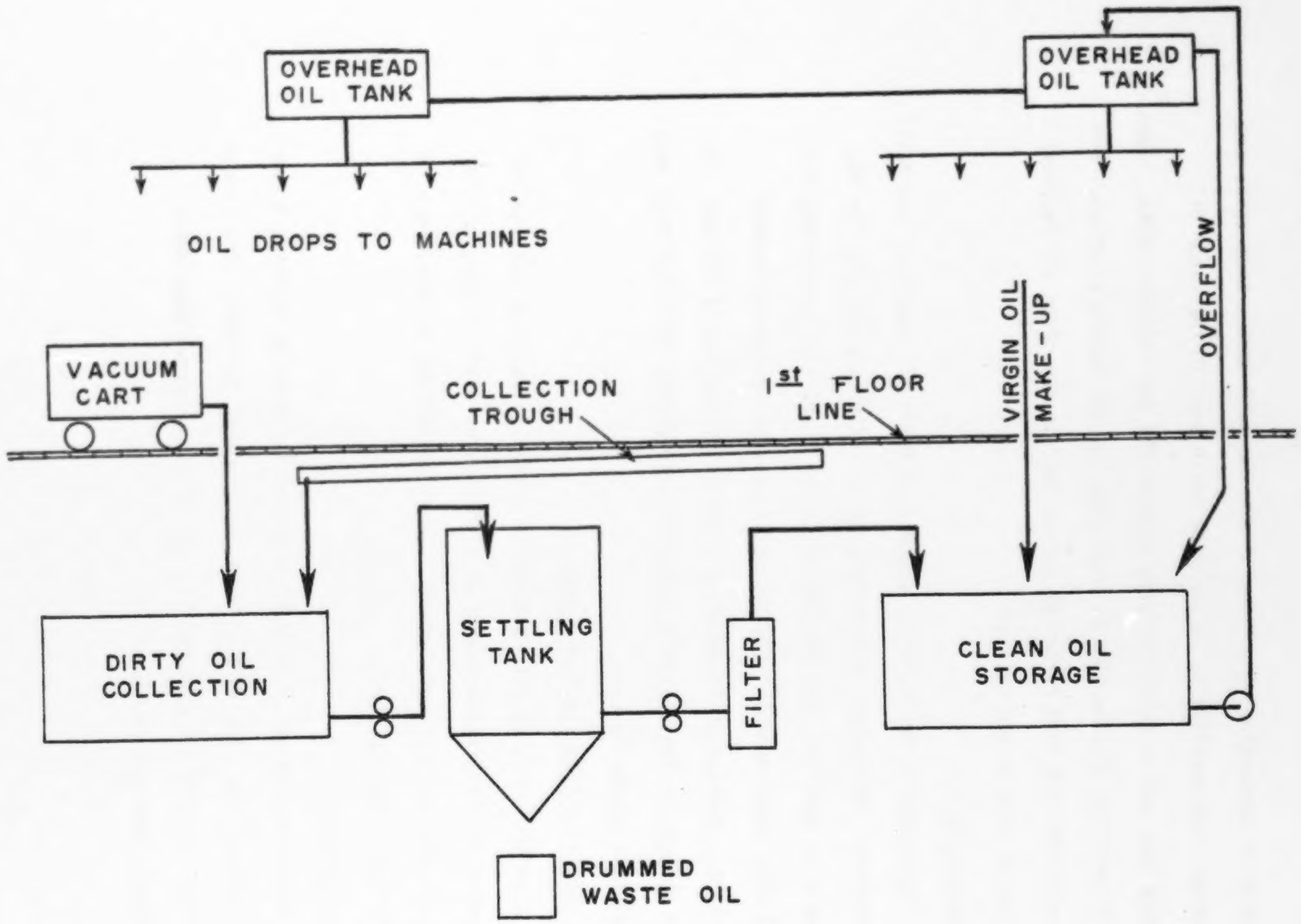
OVERHEAD OIL TANK
OVERHEAD OIL TANK
OIL DROPS TO MACHINES
VACUUM CART
COLLECTION TROUGH
1st FLOOR LINE
VIRGIN OIL MAKE - UP
OVERFLOW
DIRTY OIL COLLECTION
SETTLING TANK
FILTER
CLEAN OIL STORAGE
DRUMMED WASTE OIL

Figure III-1 Central Oil Reclamation System

Source: Russel, Burdsall & Ward (1977)

oil pump is controlled by a float in one overhead tank. Both tanks are protected from overfill by an overflow drain back to the clean oil holding tank and an equalizer pipe between the two overhead tanks. Some remote machines are supplied by drum from the oil recovery system. New oil additions are made either by direct feed to the clean oil recovery tank or by drum to the machines.

System Control

The system is periodically checked by their oil supplier, the Mobil Oil Company. Viscosity, solids content and water content are the key criteria of quality. All oil additions are a 380 sus lubricating oil, which when combined with recycled oil plus some leakage of heavier lubricants, enables us to maintain a viscosity balance of 400 sus. No major changes to the system or additive supplements have ever been made to maintain system balance.

B. Cutting Oil Reclamation System

A central cutting oil reclamation system has been in service for six years to clarify and return on a continuous basis cutting oil for several banks of cold nut formers. It is controlled to maintain a 200 to 250 sus viscosity level.

Oil Collection

Waste cutting oil is collected by gravity through trenches along both sides of the room into a steel tank located in a pit. The stream is primarily used for cutting oil, but it also carries some waste lubricants from all machines.

Oil Settling

Oil is periodically pumped up into a cone bottom settling tank of 2100-gallon capacity. Pump operating is float controlled. Clarified oil is discharged over a well around the entire perimeter of this 8' diameter tank. Bottoms are drained manually once a week.

Oil Distribution

Clarified oil overflows into a 1500-gallon holding tank. Distribution is continuous through a piping network feeding all machines within the department.

Secondary Settling

The weekly draining of bottoms from the cone settling tank are collected in a 600-gallon rectangular secondary separation tank. The tank is not heated and seven days are allowed for settling. At the weekly draw-off, approximately 25% of total volume is decanted and pumped to the clean oil tank. Periodically sludge is drained from the bottom and drummed for disposal. The tank is never completely emptied. A maximum "draw-off" would consist of about 25% good oil decanted and 25% sludge drainage. This continuous process provides a constant supply of settled oil.

System Control

Regular additions of 60 sus virgin oil are made to compensate for losses and drainage of bottoms. This thin oil is needed to compensate for the continual bleed-in of 2000 sus lubricating oils. Samples are periodically drawn for analysis by the lubricant supplier.